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ANALYSIS AND MODELING OF BACK INJURIES ABOARD U.S. NAVY VESSELS

by

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Work aboard U.S Navy vessels is often physically demanding, and personnel working in such environments are frequently at risk of back injury. Between 1994 and 1998, the U.S Navy reported 968 back injury mishaps aboard ships and submarines which resulted in 3,283 lost workdays, 5,753 days of restricted activity, and 611 days of hospitalization costing $4,758,000 in constant year 1998 dollars. The high frequency and enormous costs associated with back injury mishaps create an opportunity to increase personnel readiness and reduce operational costs through prevention. This study entailed an analysis of Afloat Special Case Mishaps for back injuries from 1 October 1993 to 30 September 1998 to develop a means of evaluating intervention effectiveness. Using descriptive statistics and categorical data analysis to measure injury arrival rates and identify back injury risk factors, a stochastic model of the back injury arrival process is developed as the foundation for event simulation. The simulation model of back injuries is then used to measure the expected outcome of interventions to reduce the number of injuries, days lost, days of restricted activity, days of hospitalization and total cost.

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ANALYSIS AND MODELING OF BACK INJURIES ABOARD U.S. NAVY VESSELS

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ABSTRACT

Work aboard U.S Navy vessels is often physically demanding, and personnel working in such environments are frequently at risk of back injury. Between 1994 and 1998, the U.S Navy reported 968 back injury mishaps aboard ships and submarines which resulted in 3,283 lost workdays, 5,753 days of restricted activity, and 611 days of hospitalization costing $4,758,000 in constant year 1998 dollars. The high frequency and enormous costs associated with back injury mishaps create an opportunity to increase personnel readiness and reduce operational costs through prevention. This study entailed an analysis of Afloat Special Case Mishaps for back injuries from 1 October 1993 to 30 September 1998 to develop a means of evaluating intervention effectiveness. Using descriptive statistics and categorical data analysis to measure injury arrival rates and identify back injury risk factors, a stochastic model of the back injury arrival process is developed as the foundation for event simulation. The simulation model of back injuries is then used to measure the expected outcome of interventions to reduce the number of injuries, days lost, days of restricted activity, days of hospitalization and total cost.

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LIST OF ACRONYMS

CNO	Chief of Naval Operations
CYxx$	Constant Year xx Dollars
DOD	Department of Defense
FYxx	Fiscal Year xx
HARP	Health and Physical Readiness Program
NAVOSH	Navy Occupational Safety and Health
NAVPERSCOM	Naval Personnel Command
NAVSAFECEN	Naval Safety Center
NIOSH	National Institute for Occupational Safety and Heath
NSC	National Safety Council
OSHA	Occupational Safety and Health Administration
SCM	Special Case Mishap
SIMS	Safety Information Management System

EXECUTIVE SUMMARY

The physically demanding work aboard U.S. Navy vessels creates an environment replete with risks of personnel injury. Required actions such as heavy lifting, moving in confined spaces, or traveling over uneven surfaces are part of the daily work routine for many Naval occupations that lead to back injury. Currently, 76% of Naval personnel who experience back injuries incur lost work time, work in a restricted duty status, and/or hospitalization. From FY94 to FY98, the Naval Safety Center received 968 Special Case Mishap reports of personnel back injury accidents. Personnel back injury accidents are analyzed for common patterns of caustic factors and outcomes as well as Human Factors involvement. Subsequently, models representing mishap events are developed. From the models, simulations are run to assess intervention effectiveness at reducing injuries, days lost, days restricted, and days hospitalized.

Categorical data analysis of mishap events describes many important features such as severity, ship type, onboard location, job action, injury mechanism and objects involved in back injuries. While one mishap resulted in a fatality, one in permanent total disability and three in the permanent partial disability of the victim, most mishaps are Class "C" or less in severity (99.48%). Aircraft Carriers and Auxiliaries (oilers, ammunition ships and repair ships) accounted for 30% and 26% of the back injuries respectively. Mishaps occur most frequently in the deck (47%), supply (15%), and engineering (11%) spaces. Injured personnel are most often handling material stores (32%), walking/steeping (21%), or installing/removing equipment (12%) at the time of injury. The E-3, E-4 and E-5 rates are typically performing such activities and account for most back injury mishaps (67%). Gender was not found to materially influence back

injury risk because enlisted women make up approximately 12.4% of the active duty population and account for 12.8% of the back injury mishaps. The injury mechanisms most often attributed to back injuries are overexertion (57%) and to a lesser extent a fall/jump from elevation (20%), or fall from the same level (13%). The objects most frequently associated with injuries involve articles being lifted/carried/moved (26%), ladders (19%), or box/barrel/containers (16%).

Between 1994 and 1998, the U.S. Navy reported 968 back injury mishaps aboard ships and submarines which resulted in 3,283 lost work days, 5,753 days of restricted activity, and 611 days of hospitalization. To measure the contributions of broad occupational categories to a model of the back injury arrival process, the mishaps are sorted into eight job families in accordance with the NAVPERSCOM organization of enlisted personnel. A pooled renewal process of the job families projected onto the arrival process for the Navy as whole is developed to model the back injury arrival process. Inter-injury times for each job family are determined to be exponential random variables with mean μ_k for each job family k. Once an injury event occurs within the job family model, the bootstrap method is employed to determine the number of days lost, days restricted, and days hospitalized. Therefore, the cost of each injury event is determined by re-sampling from the 968 observations sorted by job family to generate the number of days lost, days restricted, and days hospitalized.

The fully developed model is used to build a computer simulation of the entire back injury process. Simulations of the arrival process in a fixed state are compared with simulations of the arrival process changed due to an intervention strategy. The differences between the two states are measured in terms of injuries, days lost, days

restricted, days hospitalized and cost to measure the expected effect of interventions before implementation. Application of this simulation determined that a 30 percent Navy-wide reduction in back injuries would avoid 49 injuries, 165 days lost, 294 days of restricted activity, 31 days of hospitalization and save $174,000 (CY98$) annually.

Finally, not all categories of personnel injury mishaps have been explored. Injuries from toxic substance exposure contribute significantly to the total number of mishaps occurring annually aboard Naval ships and submarines. This study shows that mishap victims can be aggregated into job families for event modeling and simulation. Future intervention strategies can then be evaluated to determine their expected effectiveness in terms of days lost, days restricted, days hospitalized and cost..

I. INTRODUCTION

A. OVERVIEW

Many daily activities aboard U.S. Navy vessels are physically demanding. Personnel are expected to negotiate ladders, operate hatches, and traverse uneven surfaces. In addition, many occupational specialties require repetitive body movement, lifting of heavy objects, and performing tasks in awkward body positions. Personnel working in such environments are at risk of back injury. Between fiscal year 1994 (FY94) and FY98, the Naval Safety Center (NSC) received 968 mishap reports from U.S. Navy ships and submarines of personnel back injuries which resulted in 3,283 lost workdays, 5,753 days of restricted activity, and 611 days of hospitalization. The high frequency and large costs associated with back injury mishaps create an opportunity to increase operational readiness and reduce overall costs through prevention.

Back injuries significantly reduce the physical capabilities of those afflicted. Of personnel who experience a back injury, 76% will incur lost time away from the work center, time in a restricted activity status, or hospitalization according to NSC compiled data. The dramatic effect of these injuries has caused occupational health professionals to develop a multitude of potential intervention strategies with varying degrees of effectiveness. Effectiveness measurement of these interventions before implementation would enable decision-makers to prevent the most injuries possible. When determined in advance, outcomes of prevention efforts to various high-risk personnel can be targeted to those who will benefit most.

Accident investigation and reporting serve as the basic building block in the process of analyzing event occurrence. Early methods of accident investigation focused

solely on the attributes of accident victims by labeling certain groups of personnel as "accident prone" (Pimble & O'Toole, 1982). Later efforts in accident investigation analysis focused on engineering aspects of system functions rather than examining the interface of system operations with humans. More recently, trained human factors professionals have focused accident investigation on the man-machine interface of human operators to complex systems (Shappell & Wiegmann, 1997).

Analysis and investigation techniques range from basic statistical analysis of categorical data to the development of accident occurrence models (Ramsey, 1973). Analyses of this type tend to be static and do not capture the dynamics of each accident (Laughery, Petree, Schmidt, Schwartz, Walsh & Imig, 1983). While most accident reporting systems provide statistical information regarding the demographics of industrial accidents, accident descriptions are usually not compiled in any summary form (Laughery & Schmidt, 1984). Because typical reporting systems allow little discretion in recording the who, what and where of industrial accidents, information such as injury date, medical treatment, time away from work, and injury severity are usually less prone to reporting errors on the part of the investigator. Therefore, models of event occurrence based on this information should be more accurate than descriptive characteristics when used to assess changes in accident frequencies and lost productivity from potential intervention strategies. The purpose of this study is to use such information in the development of an event model to predict outcomes of proposed intervention strategies before implementation.

B. BACKGROUND

The Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat, OPNAVINST 5100.23C, establishes specific requirements for hazard awareness, identification, reporting, control and correction (DON, 1997a). In addition, it provides specific investigation and reporting procedures for mishaps occurring aboard ships and submarines (NSC, 1997). Information regarding the occurrence of each mishap is collected, recorded and submitted to the NSC via a mishap report. Mishap reports are classified as "A," "B," or "C" depending on the severity of personnel injury and/or cost resulting from the incident. The commanding officer of the responsible activity is required to submit a mishap report within 30 calendar days of event occurrence by standard format message (see Appendix A). Once received, NSC staff codes the mishap data for entry into the Safety Information Management System (SIMS).

Some types of mishap, termed "Special Case Mishaps" (SCMs), are required for all incidents, regardless of severity, involving: (1) electrical shock; (2) hazardous material, chemical or toxic exposure requiring medical care; (3) back injuries requiring medical care; and (4) explosives, oxidizers incendiaries, explosive systems or chemical warfare agent incidents (DON, 1997a). SCMs are related to personnel injuries of active duty members aboard afloat combatants and may be classified as Class A, B, or C depending on the level of loss of life and/or cost of the incident; however most do not achieve the thresholds necessary for such a classification.

Data aggregated from SCMs due to back injury are extracted from the SIMS to provide an analytical picture of each event (see Appendix B). Demographic data, such as age, occupational specialty, rank and duty station are provided for each mishap along

with categorical and numerical data, such as job action, object(s) involved, general shipboard location, days lost, days of restricted activity, days hospitalized and cost.

C. PURPOSE AND RATIONALE

The purpose of this study is to identify and evaluate those risk factors related to back injury occurrence. Once identified and evaluated, these results are used to develop a stochastic model of the back injury arrival process that quantitatively measures, in terms of days lost, days restricted, days hospitalized and cost, the expected impact of proposed intervention strategies by occupational category.

D. PROBLEM STATEMENT

The high frequency and large cost associated with SCMs reduce the operational readiness and effectiveness of Naval personnel. Injury hazards from electrical shock, toxic substance exposure or back injury are part of the daily work activities aboard U.S. Navy vessels that continuously drain personnel readiness. Because back injuries significantly diminish the physical capabilities of those afflicted, numerous prevention strategies have been developed. In order to gauge intervention effectiveness, the occupations, tasks, and personnel most at risk of back injury are identified and measured. This thesis proposes to use categorical and statistical analysis of Special Case Mishap (SCM) report data collected by the Naval Safety Center (NSC) to investigate the following questions:

1. Can back injury mishap reports be used to identify, group and prioritize occupational ratings and task performance most at risk for back injury?
2. Can a stochastic model, based on these groupings of occupational specialties, be developed to represent the back injury process?

3. Can potential intervention strategies be measured in terms of avoided injuries, days lost, days restricted, days hospitalized, and cost savings in advance of implementation?

E. DEFINITIONS

Mishaps are defined as follows (DON, 1997a):

1. Class "A" Mishap. A mishap involving one or more of the following: (1) property damage greater than or equal to $1,000,000; (2) loss of life; or (3) permanent disability.
2. Class "B" Mishap. A mishap involving one or more of the following: (1) property damage between $200,000 and $1,000,000; (2) permanent partial disability; or (3) hospitalization of five or more people.
3. Class "C" Mishap. A mishap involving one or more of the following: (1) property damage between $10,000 and $200,000; (2) an injury preventing an individual from performing regularly scheduled duty or work beyond the day or shift on which it occurred; or (3) nonfatal illness or disability causing loss of time from work or disability at any time.
4. Class "D" Mishap. Special Case Mishaps (SCM) not meeting the reporting criteria of Class A, B, or C.

F. SCOPE AND LIMITATIONS

This study examines SCMs of all levels of severity related to back injury of active duty personnel assigned to ships and submarines from October 01, 1993 through September 30, 1998. No NAVOSH reporting requirement exists for commands providing support functions ashore; therefore, comprehensive back injury data for U.S.

Navy personnel assigned to other than afloat platforms is unavailable. With the above limitations taken into consideration, 968 mishap reports were extracted from SIMS for the present study. The next chapter establishes a foundation for understanding the anatomy, risk factors, occupations, and reporting of back injuries in general and as applicable to shipboard personnel. A discussion of the methodology used in this study is provided in Chapter III. Results of statistical analysis and stochastic model development are provided in Chapter IV. Chapter V concludes this study by providing a research summary, conclusions, and recommendations for further study.

II. LITERATURE REVIEW

A. OVERVIEW

To establish a framework for a model of back injury occurrence and intervention evaluation, an understanding of the anatomy of the back, the risk factors that lead to injury, injury prevention, contemporary models of accident causation, and the strengths and weaknesses of accident reporting is necessary. This chapter provides a thorough review for the identification and measurement of the pertinent factors in the back injury processes which impact personnel aboard U.S. Navy vessels. In addition, current models of accident causation are evaluated to provide a theoretical footing for intervention measurement. To aid model development, personnel are categorized in accordance with their common physical activities to aid the development of a stochastic model of the injury arrival process. Finally, the strengths and weaknesses of accident reporting systems are discussed to focus model development on those events that are determined to be most reliable.

B. BACK INJURIES

1. Definition

According to the National Institutes of Occupational Safety and Health (NIOSH) (1991) musculoskeletal injuries are:

> Both acute and chronic injuries to muscles, tendons, ligaments, peripheral nerves, joint structures, bones and associated vascular system. These injuries may be reported as sprains, strains, inflammations, irritations, and dislocations. In the medical literature, this broad class of physical symptoms or complaints is often referred to as wear-and-tear disorders, overuse or overexertion injuries, osteoarthritis, degenerative joint diseases, chronic microtraumas, repetitive strain injuries and cumulative trauma disorders. (p. 1)

This research focuses on one segment of musculoskeletal injuries that are reported in accordance with the NAVOSH Program Manual for Forces Afloat as back injuries. The SCM serves as the incident-reporting tool for the present study. NIOSH (1997) also defines back injury reports by saying:

> Back “incidents “ or “reports” include conditions reported to medical authorities or on injury/illness logs; these may be symptoms or signs that an individual has determined the need for medical or other attention. They may be acute symptoms, chronic pain, or injury related to a particular incident, and may be subjectively or objectively determined. (p. 6-3)

The intent of reporting requirements in the NAVOSH Program Manual for Forces Afloat is to serve as the incident reporting mechanism for all personnel injuries. The back injury SCM is the NIOSH equivalent of a back injury report defined above.

2. Anatomy and Physiology

An understanding of the anatomy of the back and the physical forces imposed on the spine is necessary to properly evaluate the risk of back injury. The human spine is made up of small bones or vertebrae. The vertebrae are stacked on top of each other to form a column, and between each vertebra is a cushion called a disk. Figure 1 displays the vertebra and disks of the human spine.

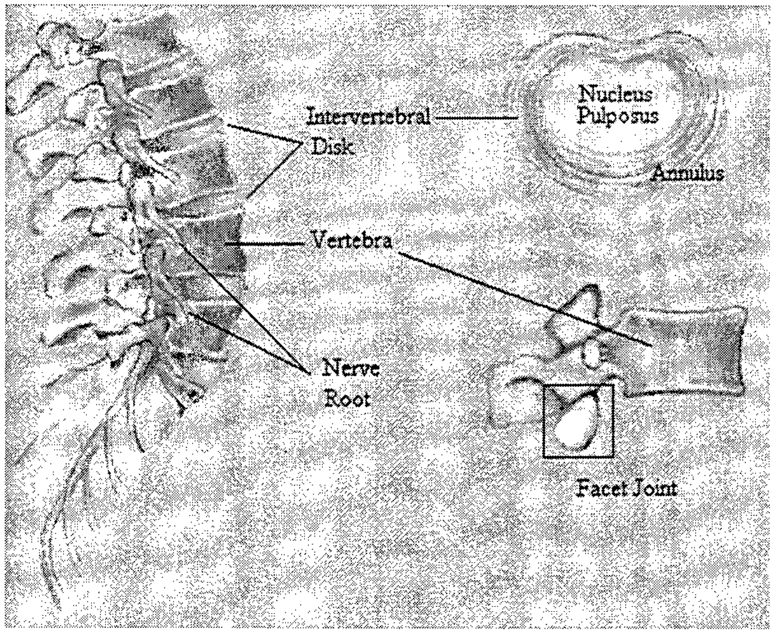


Figure 1. Spinal Column Diagram

The vertebrae are held together by ligaments, and muscles are attached to the vertebrae by bands of tendons. Openings in each vertebra line up to form a long hollow canal. The spinal cord runs through this canal from the base of the brain. Nerves from the spinal cord branch out and leave the spine through the spaces between the vertebrae. Hence, the spine protects the spinal nerves and column as depicted in Figure 2. (Oklahoma State University, 1998).

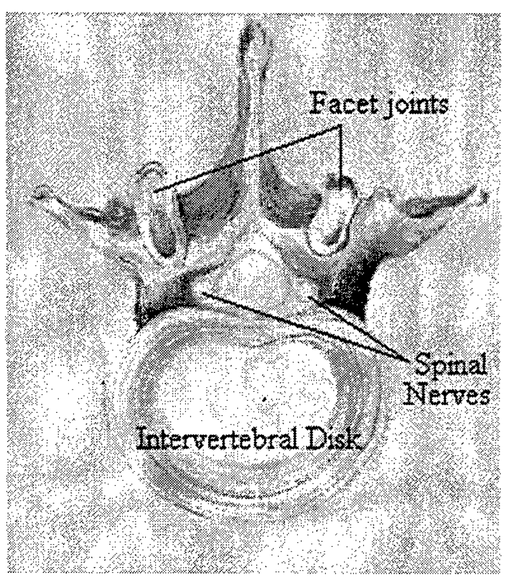


Figure 2. Cross-Section

Because the lower part of the back holds most of the body's weight, minor problems with the bones, muscles, ligaments, or tendons in this area can cause pain when a person stands, bends, or moves about. Less often, a problem with a disc can pinch or irritate a nerve from the spinal cord, causing pain that runs down the leg below the knee, called sciatica (Medical Multimedia Group, 1998). Every time humans bend or move, the discs of our back compress with the motion of the spine. Over time, the stress of bending or lifting heavy objects can damage the components of the back and spine.

3. Risk Factors

Most back injuries result from one of two sources. The first type of injury (an acute injury) results from a single strenuous event that damages the intervertebral disk due to overexertion. The second type results from cumulative trauma disorders or physical impairments due to chronic, or accumulative, effects of work-related repetitive microtrauma to the musculoskeletal system (Mital, 1997). Jobs that repeatedly require personnel to place their bodies and extremities in awkward postures are most likely to cause cumulative trauma disorders. Professions such as nursing or truck driving, for example, which require heavy, repetitive lifting, vibration exposure, awkward positions and sitting for long periods of time are most at risk for low back injury (Fernberg, 1998). Even though it is generally agreed that cumulative trauma disorders of the upper extremities and the lower back are the most pervasive work-related injuries, accurate injury data associated with this category of injury is difficult to acquire.

Research at Oklahoma State University (1998) identifies many factors which contribute to the risk of back injury including (1) poor physical condition, (2) poor posture, (3) extra weight, (4) stress and (5) overexertion. Good physical condition in

general is important because stomach muscles provide much of the support needed for the spine. Weak and flabby stomach muscles may not provide all of the support necessary, especially when lifting, for the back to support the task at hand. To reduce the erosion of the disks in the spinal column, good posture allows the back to maintain a natural "S" shape depicted in Figure 1. Extra weight increase the stresses and forces required for bending and lifting tasks, which increases the pressure between disks leading to more frequent injuries. Stress may cause tense muscles to be more susceptible to strains, sprains and spasms. Therefore, as supported by Marcinik (1986), people in occupations that require heavy lifting are more prone to overexerting the back beyond its physical limitations and to higher incidences of back injuries.

4. Cost

Although exact estimates vary according to industry, classification of injury, and data source, back injuries are commonly recognized as one of the most widespread and expensive occupational injuries. According to the National Safety Council (1990), 31 percent of all injuries in the workplace are musculoskeletal overexertion injuries; 22 percent of all injuries are overexertion injures of the lower back. When back pain is considered, the problem becomes enormous. Muir (1994) states that a staggering 80 to 90 percent of all Americans will suffer from lower back pain at some point in their life while 60 to 80 percent of these people will find pain at work. Personnel who injure their backs are four time more likely to suffer from back pain again (Muir, 1994).

The published literature does not provide separate cost estimates for back injuries and back pain. However, according to a study by Schwind, industry-wide figures show the cost per incident of injury causing compensatable back pain rising from around

$3,000 in 1967 to just under $7,000 in 1994 (1994). In addition, William S. Marras, professor of ergonomics at Ohio State University, states, "the cost per injury is staggering, nearly $40,000 for the average case in the state of Ohio" (1996). Mital (1997) reports that back pain costs in 1984 were approximately $16 billion; lost wages accounted for approximately $2.5 billion of this cost. In addition, the cost of surgical back procedures alone exceeds $12 billion annually. Because surgical procedures remove the employee from the job for lengthy periods of recuperation and therapy, and in many cases permanently from heavy lifting occupations, they exact an enormous toll in work-related injury expenses to the employer.

According to Fernberg (1998), 10 percent of people who do not recover from back injuries account for 90 percent of the cost expended for such injuries. The total annual cost, using health care industry practices to estimate the indirect costs, which are considered 4.5 times the direct costs, would be approximately $126 billion in 1985. Using Mital's conservative annual increase of 8 percent in health care costs due to inflation, total cost of back problems in the United States can be estimated to be in the hundreds of billions per year.

C. HUMAN FACTORS OF BACK INJURIES

1. Causation Modeling

The human, machine and environmental components of the work setting which interact to form a system producing accidents or injuries lies at the foundation of systems theory of accident causation (Firenzie, 1971). Interactions among these components can increase or decrease the probability of an accident or injury occurring. Firenzie (1978) developed the most popular systems theory model whose primary components are the

person/machine/environment, information, decisions, risks, and the task to be performed. The premise of the model is that a person must interact with a machine or tool in the environment when performing a task. Prior to performing the task, the person must collect information, weigh risks, and decide whether or not to perform the task. He also asserts that factors which must be considered when collecting information, weighing risks, and making decisions include: (1) job requirements; (2) the worker's abilities and limitations; (3) what is gained if the task is successfully accomplished; (4) what is lost if the task is attempted but fails; and (5) what is lost if the task is not attempted. An understanding of these factors enhances the decision-making process of a worker and allows for a more favorable interaction of system components within the work environment.

The epidemiological theory of accident causation developed by Suchman (1961) holds that models used for studying and determining the causal relationship between environmental factors and disease (epidemiology) can also be used to study causal relationship between environmental factors and accidents.

> According to this approach, injuries and damage are the measurable indicies of an accident, but the accident itself is the unexpected, unavoidable, and unintentional act resulting from the interaction of victims of the injury or damage deliverer and environmental factors within situations which involve risk taking and perceptions of danger. ... In applying this approach one seeks an explanation for the occurrence of accidents within the host (accident victim), the agent (injury or damage deliverer), and enviromental factors... (p.50)

The key components of these environmental factors are predispositional and situational characteristics. Predispositional characteristics consist of susceptibility of people,

perceptions, and environmental factors. Situational characteristics include risk assessment by individuals, peer pressure, priorities of supervisors, and attitude.

M. Edwards (1981) described an approach for conducting accident investigations with an emphasis on human factors using a model of accident causation called the SHEL system developed by E. Edwards (1972). Three types of system resources, Software (procedures and rules), Hardware (machinery), and Liveware (humans) interact together within the work Environment. M. Edwards (1981) wrote:

> The ergonomics approach to accidents is based on the premise that what people do in a work situation is determined not only by their capabilities and limitations, but also by the machines they work with, the rules and procedures governing their activities and the total environment within which the activity takes place. ... Accidents, then, are symptomatic of a failure in the system and as such provide clues about the location of the source of failure, indicating where mismatches occur and what kind of action is likely to be effective in reducing these mismatches. (p. 114)

Back injuries are the result of a mismatch between the human capabilities and task requirements in an environment predisposed to injury risk. Interventions designed to prevent back injuries, therefore, are aimed at improving the interface of the human to the job.

2. Prevention Strategies

Back injury reduction efforts have focused on screening, physical conditioning, education and re-engineering of machinery and systems to reduce both the time and effort necessary to perform lifting and movement tasks. According to Marcinik (1986), the requirement for muscular strength still exits in many Navy occupations. Task analyses have found the ratings of Boatswain's Mate (BM), Gunner's Mate (GM), Hull Technician (HT), and Machinist Mate (MM) to be among the most physically demanding of Navy

occupations. The performance of tasks in these ratings requires high levels of muscular strength and endurance.

Initial prevention efforts focused on development of specific physical qualifications for personnel who performed heavy lifting functions. Marcinik (1986) states that since occupational strength standards do not currently exist for Navy jobs, personnel will continue to be assigned to jobs where task requirements exceed strength abilities, thus increasing their risk of sustaining back injuries. This problem has gained additional relevance in the Navy as more women are assigned to shipboard jobs in so-called nontraditional occupations (Marcinik, 1986).

The changing demographics of the Navy workforce may impact the rate at which injuries occur. One research study investigating the relationship between low back injury and occupation surveyed 3317 male and female subjects in eight occupations (Magora, 1977). In heavy industrial jobs, 19.1% of the males and 35% of the females experienced lower back injuries. This study indicates that the sex of the subject may play a role in the causation of back injuries, possibly through inadequate physical ability in a physically demanding occupation. Furthermore, research by Hoiberg (1980) compared total hospitalization rates between enlisted Navy men and women and found that Navy women experience higher hospitalization rates for musculoskeletal type injures than men both in traditional and in nontraditional occupations. This study suggests that in order to maximize the efficiency of personnel classification, strength standards need to be developed for each occupational specialty.

Current recruiting and accession trends in the U. S. Navy suggest that women will continue to make up more of the active duty force. If present trends continue, as reported

by Weible (1998), the pool of potential recruits in 2003 will reach about 4 million, of which 2.05 million men and 1.95 million women will compete for jobs which are now almost entirely gender-neutral. In 1997, women made up 14.2 and 12.4 percent of the active duty officers and enlisted personnel up from 6.3 and 4.2 percent respectively in 1977 (Weible, 1998).

The repetitive nature of the lifting tasks associated with many jobs will continue to take a significant toll on those physically qualified personnel. In addition to introducing proper selection criteria, Marcinik (1986) has suggested that a realistic approach is to develop strength conditioning programs to close the gap between task requirements and personnel strength abilities. Physically demanding jobs would generally require equally demanding conditioning programs to ensure personnel are always capable of satisfactory performance.

Specific strength conditioning programs may be the most cost-effective alternative to the Navy in terms of reducing the risk of injury and of increasing the work efficiency and productivity of Naval personnel. Marcinik (1986) also believed that well-designed physical training programs could substantially reduce both the frequency and severity of back injuries. He theorized that physical conditioning programs increasing muscular strength, endurance, cardio-respiratory fitness, and flexibility of personnel will reduce back injury frequency. This added fitness better prepares the individual to meet the excessive physical stresses commonly experienced while performing heavy lifting tasks. In addition, he recommended strength conditioning programs: (1) at the recruit training level to prepare young men and women for the physical demands of shipboard work; (2) for shipboard use so that newly acquired strength can be maintained during

extended sea duty; (3) for especially physically demanding and hazardous occupations to reduce the risk of injuries; and (4) for women, in order to improve upper torso strength capabilities, thereby enhancing job performance in physically demanding positions.

Back education has become a popular treatment and prevention strategy because of its comparatively low cost and assumed benefits. As a treatment approach, the effectiveness of back-care education has shown mixed results according to Woodruff, Conway and Bradway (1994). They state that positive effects have been reported on a variety of outcome measures such as lost work days, pain assessments, symptom reduction, health care utilization, knowledge, observed body mechanics and physical capabilities. They state that a sizable number of studies report no long-term differences between groups of back patients undergoing back education versus control patients. A general conclusion of several investigators has been that back education as a prevention strategy is probably more effective in helping avoid subsequent back pain episodes but has little effect on preventing initial incidents. Regardless of the undetermined effect of back injury prevention education on health outcomes, back education remains an accepted and relatively inexpensive prevention weapon against back injuries.

In conjunction with the Navy's efforts to enhance military readiness and the quality of life of Navy personnel, a comprehensive health promotion program has been implemented that stresses the need for healthy lifestyles and reduction of health risk factors. Back injury prevention is one of seven health promotion program elements. Woodruff et al. (1994) found that lifting, bending and health/fitness status were related to back problems of service members. With these findings in mind, a separate area of the back injury prevention program is to provide assistance in the development and

maintenance of proper back-care habits among Navy personnel for the purpose of avoiding painful and expensive injuries. The program concentrates on presenting information regarding back mechanics and safe lifting techniques with an emphasis on prevention. By providing service members with correct lifting and bending techniques, the program may help avoid initial and recurring back injury episodes. Furthermore, the promotion of health and fitness among service members is the primary focus of the Navy's Health and Physical Readiness program (HARP). To the extent that the HARP program is effective in improving and maintaining the physical health and fitness of service members, Woodruff et al. (1994) found that an additional positive impact on back injury also may be achieved.

While the concept of training to lift safely appears valid, according to Mahone (1994), the results have been poor. Uninjured workers are difficult to motivate, the quality of training varies widely, and compliance is sketchy. Mahone (1994) continues to explain that part of the reason that training has failed to significantly reduce the cases of back injury is that safe lifting is not a natural way to lift. The only prevention strategy that can provide direct intervention on the true nature of the problem is changing the manner in which people perform specific tasks within their job. Proper job design helps improve the human-machine interface by re-engineering the heavy lifting task out of the job. Many employers would like to avoid job design changes, assuming that such changes will be difficult, expensive, or disrupt operations. Mahone (1994) found that about two-thirds of back injuries are preventable. As stated above, the costs of allowing preventable injuries to occur are staggering and increasing with medical costs in general. For employers, these costs will continue year after year unless faulty work designs are

corrected (Mahone, 1994). The result is that workers are routinely required to lift beyond the physical limits of spinal disc compression, and injuries occur.

The NIOSH has developed guidelines for manual lifting and lowering. For each job, lifting and lowering information is collected and inserted into NIOSH equations, usually by computer, to determine which lifting jobs are hazardous and why. Since the NIOSH model indicates which worksite factors are influencing a recommended weight limit, options for modifying the job become apparent, and proposals to reduce the hazard can be tested and built into tasks of the job (Mahone, 1994). By systematically reviewing the physical task requirements of each job, employers can identify, redesign and reorganize those jobs that are considered hazardous and which bring a high risk of back injury to the employee.

Intervention strategies aimed at prevention of back injury are often measured and implemented across organizational functions or occupations. Lovested (1994) recently studied the effects and proposed prevention alternatives of back injuries on operators of machine tools. Recognizing the task similarities within and between personnel ratings in diverse military functions, aggregation becomes necessary to develop a more parsimonious grouping of occupational specialties for meaningful model development. Aggregating episodes of accidents based on similarities of job classification, physical task performance and hazard exposure into job families was successfully used by Schmidt and Petree (1984) to measure accident rates. Such activities will be necessary in the present study to facilitate modeling and analysis for back injuries to Naval personnel.

D. JOB FAMILIES

In order to develop a comprehensive system for analysis, modeling and measurement of back injuries, personnel will be organized according to generalized job families. A job family is simply a group or cluster of jobs that are in some manner inter-related. Pearlman (1980) has long recognized the need for such classifications in a number of different areas of research for both theoretical and practical reasons. As is consistent with the assertions made by Pearlman, Farina (1973) points out the eventual need for developing a theoretical structure applicable to entire jobs rather than to more molecular work units (e.g. individual tasks). Jobs are typically not composed of such single work units; rather it is the totality of all such elements existing in combination and interacting over a period of time that underlies the concept of a job. Such a taxonomic system is essential for improving our ability to integrate existing research results and to generalize previous findings to new settings and applications (Pearlman, 1980).

Accident occurrence modeled as discrete events which occur to a particular job family would facilitate the organization of back injury data to provide useful descriptive statistics and provide the foundation for modeling the injury arrival process. Fleishman (1975) notes that a system of behavior classification (of which job families are an example) is generally not viewed as an end in itself but rather is regarded as a tool to aid in interpretation or prediction of performance by illuminating relationships between whatever is classified and other variables of interest. In order to streamline administrative and functional management of the vast array of occupational specialties, the U.S. Navy Personnel Command (NAVPERSCOM) has undertaken a massive effort to organize enlisted personnel ratings into associated communities. Communities are

developed based on similarities in job activities, organizational supervision and fundamental training activities. As listed in Table 1, the job families for the purposes of this study are grouped in accordance with the NAVPERSCOM organization of enlisted personnel.

NAVPERSCOM Code	**Job Family**	**Occupational Specialties**
PERS-402	Hull and Engineering	• Boiler Technician (BT) • Damage Control (DC) • Electrician's Mate (EM) • Engineman (EN) • Gas Turbine System Technician (GS) • Hull Maintenance Technician (HT) • Interior Communications Electrician (IC) • Machinist's Mate (MM) • Machinery Repairman (MR) • Patternmaker (PM)
PERS-404	Aviation	• Aviation Boatswain's Mate (AB) • Air Traffic Controller (AC) • Aviation Machinist's Mate (AD) • Aviation Electrician's Mate (AE) • Aerographer's Mate (AG) • Aviation Storekeeper (AK) • Aviation Structural Mechanic (AM) • Aviation Ordnanceman (AO) • Aviation Support Equipment Technician (AS) • Aviation Electronics Technician (AT) • Aviation Antisubmarine Warfare Operator (AW) • Aviation Maintenance Administrationman (AZ) • Photographer's Mate (PH) • Parachute Riggers (PR)
PERS-405D	Deck	• Boatswain's Mate (BM) • Master at Arms (MA) • Quartermaster (QM) • Signalman (SM)
PERS-405E	Supply	• Disbursing Clerk (DK) • Lithographer (LI) • Mess Management Specialist (MS) • Postal Clerk (PC) • Ship's Serviceman (SH) • Storekeeper (SK)

Table 1a. Job Families by Occupational Specialties

NAVPERSCOM Code	Job Family	Occupational Specialties
PERS-406	Technical	• Data Systems Technician (DS) • Electronics Technician (ET) • Fire Controlman (FT) • Gunner's Mate (GM) • Mineman (MN) • Missile Technician (MT) • Operations Specialist(OS) • Ocean Systems Technician (OT) • Opticalman (OM) • Radioman (RM) • Sonar Technician (STG) • Torpedoman (TM) • Weapons Technician (WT)
PERS-405C	Other (Administration)	• Data Processing Technician (DP) • Draftsman Illustrator (DM) • Journalist (JO) • Legalman (LN) • Navy Counselors (NC) • Personnelman (PN) • Religious Program Specialist (RP) • Yeoman (YN)
PERS-407	Other (Medical)	• Hospital Corpsman (HM) • Dental Technician (DT)
PERS-408	Other (Electronic Warfare)	• Cryptologic Technician (CT) • Intelligence Specialist (IS) • Electronic Warfare Technician (EW)

Table 1b. Job Families by Occupational Specialties (continued)

Job family organization of back injury mishaps provides a parsimonious aggregation by which the generalities of task performance can be applied in the broader context of a typical work environment. An analysis by Laughery and Schmidt (1984) found that 72% of back injuries are due to overexertion. They suggest that interventions can be focused on the design of tasks and the limitations of employees who perform them. Model development and analysis by the numerous occupational ratings listed in Table 1 would prove unwieldy and yield results too specific to be of any practical use for decision-makers for intervention implementation. Aggregation by job family will allow

for more direct comparison of findings from industrial studies and provide decision-makers with broader populations to target intervention strategies.

E. INVESTIGATION AND REPORTING

Accident investigation is primarily concerned with producing information that leads to identification of the principal factors contributing to an accident (Sciretta, 1999). Once these factors are identified, corrective actions can be taken to prevent similar accidents or injuries from occurring in the future. The quality of the accident investigation process and the information obtained from it will determine the success of corrective measures (Hill, Byers, Rothblum, & Booth 1994). Because the effectiveness of preventive measures is directly related to the quality of the investigation, Raby and McCallum (1997) point out that it is imperative that accident investigators be properly trained in accident investigation procedures.

Personnel conducting accident investigations range from untrained indivuals with limited resources working alone to large investigative teams of experts with unlimited resources (Ferry, 1988). Typically, accident investigations are conducted by personnel with very little training or background in investigative procedures (Ferry, 1985). As explained by Sciretta (1999), when personnel injuries occur in Navy Units, investigative personnel are required to produce properly formatted reports. These personnel injuries may range from a work-related injury occurring on-duty to a motorcycle accident off-duty. Normally, the investigation and reporting requirements are randomly assigned to an available officer stationed at the unit who typically possesses no training in investigative procedures (Sciretta, 1999). In addition, Benner (1982) determined that accident investigators tended to have preconceived notions and perceptions that cloud

their judgement when performing investigations. Preconceived notions and perceptions by the investigators, coupled with inadequate training, can lead to an investigation process that focuses on placing blame rather than correcting unsafe conditions.

The accident investigation process must culminate in a comprehensive, unbiased and factual accident report (Goetsch, 1996). Safety professionals are faced with two primary tasks when producing accident reports. They must produce reports required by appropriate statute and must provide reports useful to an effective safety program (National Safety Council, 1975). Adams and Hartwell (1977) found evidence indicating that many accident-reporting systems are not producing factual information databases, but have become an alternate means of achieving individual or organizational needs and preferences.

Any event model of the accident process is only as good as the reporting processes and reports from which it came (Edwards, 1981). According to Sciretta (1999), contemporary accident reports produce relatively accurate information regarding the who, what, and when of the incident (1999). This type of information is generally regarded categorical or numerical, and offers little subjectivity in the reporting process. For this reason, models based on inter-event times or other numerical data would be less likely to reflect the biases of those who produced the reports.

F. SUMMARY

The human and economic toll extracted from the U. S. Navy due to back injuries is large. Lost productivity, treatment, rehabilitation, and medical disability expenses due to such injuries all impose a tremendous financial burden. Although the fundamental nature of shipboard life may forever make sailors prone to the occurrence of such

injuries, a discrete model of the contributing factors related to the occurrence of back injuries would provide decision makers with a powerful tool to evaluate the potential outcome of numerous prevention strategies. Such a model could provide useful insight in evaluating the effects of changes in screening qualifications, job designs, and training options before systematic intervention strategies are implemented.

While injury prevention and cost avoidance are important organizational goals in general, the need for systematic analysis of the trade-off between the two efforts is ever more important. Of particular interest in this study are identification and measurement of the risk factors associated with back injury in a shipboard environment. Understanding the nature of back injury occurrence in general is a fundamental first step that provides the basis for segmenting the organizational occupations into more meaningful job families. Modeling the back injury arrival process based on job families emphasizes, and is consistent with the occupational, organizational, and supervisory actions available for prevention efforts. The job family model of the back injury arrival process will provide a tool to measure future prevention activities before resources are applied to uncertain outcomes.

III. METHODOLOGY

A. RESEARCH APPROACH

This study involves the analysis of all SCM reports maintained by the NSC in SIMS. SCM Reports contain specific data for each episode of back injury to active duty personnel requiring medical attention while assigned aboard ships and submarines. Descriptive statistics and categorical data analysis are used to identify and evaluate those risk factors related to back injury occurrence. A stochastic model of back injury event occurrence is developed to predict event frequency and severity by job family. Once appropriate prevention strategies are identified, interventions are applied to determine the new injury arrival rate. Model comparison of the back injury process with the unchanged arrival rate to the changed arrival rate is used to predict effectiveness in terms of injury frequency, days lost, days restricted, days hospitalized, and cost.

B. DATA COLLECTION

1. Special Case Mishap (SCM) Reports

In accordance with OPNAVINST 5100.19C (Department of the Navy, 1997), SCM reports are required for specific incidence of personnel injury related to electrical shock, hazardous material exposure, back injuries requiring medical care, and explosives. The commanding officer of the responsible activity is required to submit a mishap report within 30 calendar days of event occurrence by standard format message. SCM reports contain demographic data, such as age, occupational specialty, rank and duty station, along with categorical and numerical data, such as job action, object(s) involved, general shipboard location, cost, days lost, days of restricted work activity, days hospitalized and cost for each mishap.

2. Safety Information Management System (SIMS)

In accordance with the NAVOSH Program Manual for Forces Afloat, the NSC maintains a relational database of personnel injury mishaps. Back injury mishaps requiring medical attention are reported via SCM reports in the form of standard format messages (Appendix A). Once received, NSC staffs code and enter the mishap data into SIMS. A review of records available at the NSC in SIMS of SCM related to back injury occurring from October 01, 1993 through September 30, 1998 retrieved 968 mishap reports for the present study.

3. Procedure

Data extraction from the query of all back injury mishaps reported in SIMS is accomplished with the Monarch data access and analysis tool (1995). SCM reports for back injuries are provided in ASCII text format. Using Monarch, a model of field names, lengths and data types is developed to remove the appropriate information from ASCII-based SCM reports for analysis in S-Plus (1997) and Microsoft Excel 97 (1997). The tables generated consist of individual back injury incidents by row with each column containing individual fields of descriptive and categorical data. Fields for consideration in the present study include event serial number, date, severity, environment (ship or submarine), rank, rating, sex, age, permanent duty station, hull type, parent/type command, overall injury, body part and location, diagnosis, cost, days hospitalized, days of restricted activity, days lost, specific shipboard location of mishap, job action, experience, object(s) involved, accident type, and a brief narrative of the event.

To measure the contributions of broad occupational categories to the overall arrival process of back injuries, the data set is sorted into eight job families. Job families

are developed in accordance with the NAVPERSCOM organization of enlisted personnel and are grouped by specialty rating provided in Table 1 as: Engineering, Aviation, Deck, Supply, Technical and Other (to include the Medical, Administrative, and Electronic Warfare specialties). In addition, the job families of Seaman and Fireman are added to account for non-specialized personnel. Officers and Marine Corps personnel are grouped in the "Other" job family for arrival process formulation.

C. DATA ANALYSIS

Descriptive statistics and categorical data analysis of back injury mishap data are used to identify and evaluate those risk factors related to back injury occurrence. Injured personnel are grouped into job families to represent those occupations that share common workplace risks of back injury. A stochastic model is built to simulate the arrival process of back injuries by job family and to measure the effects of future intervention strategies. Prevention strategies are evaluated in terms of injury frequency, days lost, days of restricted activity, days of hospitalization, and cost as alternatives to investing scarce resources in back injury intervention strategies.

IV. RESULTS

A. BACKGROUND

The average number of back injury mishaps occurring to active duty personnel per year during FY94 – FY98 appears stable. Figure 3 displays the average number of back injury mishaps per 1,000 active duty personnel from FY94 through FY98. The average yearly number of back injury mishaps across FY94 – FY98 was 1.68 per 1,000 active duty personnel. Figure 4 displays the average number of back injury mishaps per ship from FY94 through FY98. The average yearly number of back injury mishaps across FY94 – FY98 was .73 per ship.

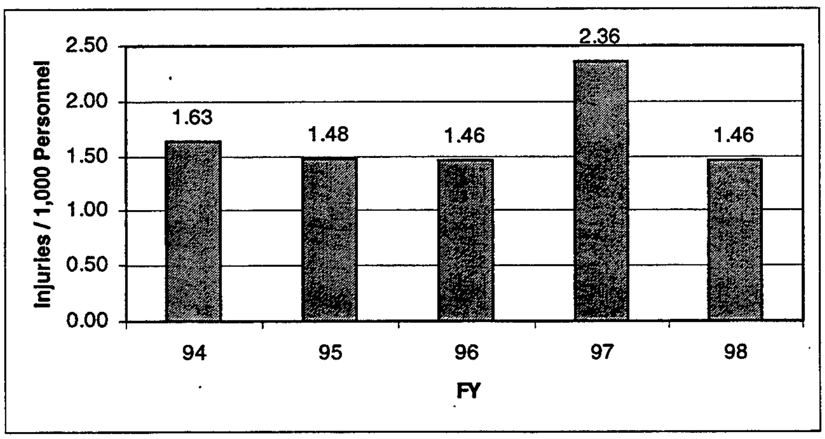


Figure 3. Average Number of Back Injuries per 1,000 Active Duty Personnel by FY

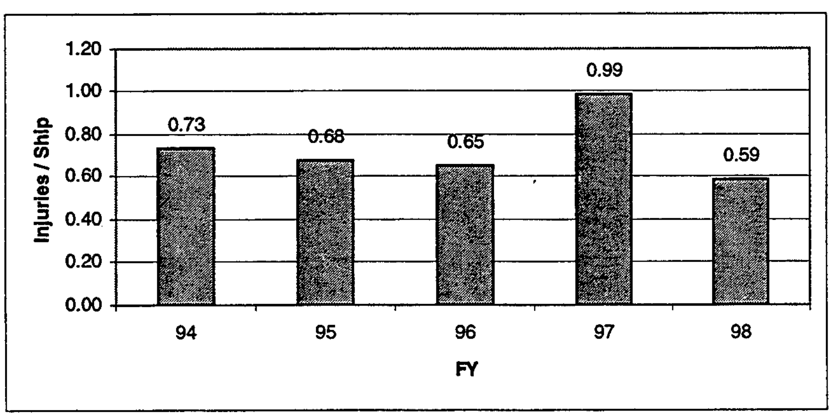


Figure 4. Average Number of Back Injuries per Surface Ship by FY

The effects of defense reduction efforts on active duty personnel levels and surface fleet size are displayed in Figure 5. In 1994, approximately 124,500 personnel supported the operations of 277 ships. Over the 1994 – 1998 period, personnel levels dropped 15% to 105,000 and surface ships dropped 6.1% to 260. When compared on a percentage basis, this reduction indicates that the U.S. Navy is expected to carry out future missions with fewer ship and personnel assets. With a relatively stable back injury mishap rate, the FY94 – FY98 data was utilized for categorical data analysis to identify underlying trends of importance to occupational health professionals. In addition, the relevant factors necessary for model formulation will be identified and explored.

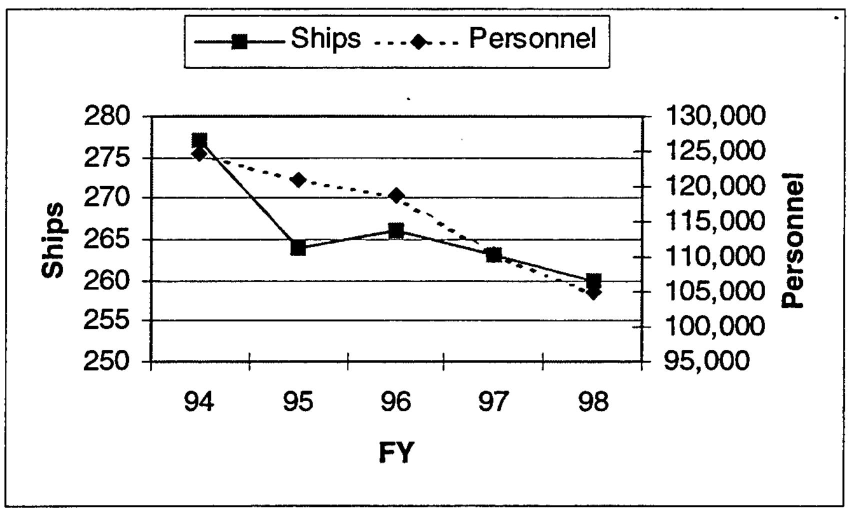


Figure 5. Ship and Active Duty Personnel Levels by FY

B. DATA EXPLORATION

Between FY94 and FY98 there were 968 reported back injury mishaps. The Navy classifies mishaps according to accident severity depending on the dollar value reached and/or involvement of personnel fatalities/injuries (see definitions page on 4). Mishap severity includes: 2 Class A (.21%), 3 Class B (.31%), 435 Class C (44.94%) and 528 Class D (54.55%). It should be noted that both Class A back injury mishaps

involved fatalities caused by falls from great heights. As shown in Table 2, most back injury mishaps are of Class C or D.

Severity	94	95	96	97	98	Totals	Percent
A	1	0	1	0	0	2	0.21%
B	1	0	1	1	0	3	0.31%
C	98	76	85	110	66	435	44.94%
D	103	103	86	149	87	528	54.55%
Totals	203	179	173	260	153	968	100.00%

Table 2. Back Injury Mishap Severity by FY

As organized by Sciretta (1999, p. 37), ship type can be divided into five categories: Carriers, Combatants, Amphibs, Auxiliaries, and Other. Out of the 968 back injury mishaps, "Carriers" account for 284 (30%) of the back injuries. "Auxiliaries" (oilers, ammunition and repair ships) account for 247 (26%) of the mishaps. The remaining distribution of back injuries are as follows: 169 (17%) on "Combatants" (cruisers, destroyers, frigates, and submarines), 168 (17%) on "Amphibs" (helicopter, equipment, and troop transport ships), and 100 (10%) on "Other" (patrol craft, mine counter-measure, diving ships and unkowns). A classification of the back injury mishap data by ship type is provided in Figure 6.

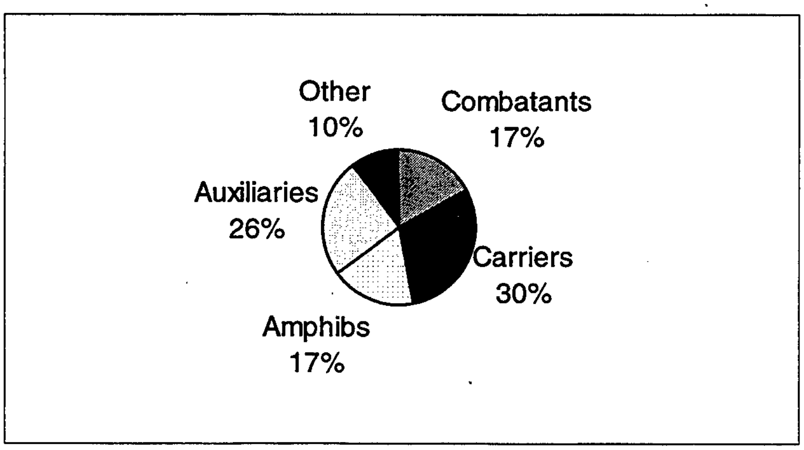


Figure 6. Percent of Back Injuries by Ship Type

Data from each back injury mishap event also indicate the general location on the ship where each injury occurred. Of the 968 mishaps reported, 457 (47.21%) occurred in the deck spaces, 141 (14.57%) in the supply spaces, 107 (11.05%) in engineering spaces, 73 (7.54%) in habitability spaces, 70 (7.23%) in aviation spaces, 35 (3.62%) in weapons spaces, 34 (3.51%) on the pier and 51 (5.27%) in other spaces. Injuries by job action of the personnel in those areas are: 307 (31.71%) handling material stores, 201 (20.76%) walking/stepping, 114 (11.78%) equipment installation/removal, 46 (4.75%) housekeeping, 36 (3.72%) handling lines and 264 (27.27%) other actions. Frequent injuries are occurring in deck spaces to personnel handling material stores or walking. Tables 3 and 4 provide a tabulation of the general shipboard area and job action of personnel involved in back injury mishaps.

Location	94	95	96	97	98	Totals	Percent
Deck Spaces	93	72	73	126	93	457	47.21%
Supply Spaces	25	26	28	45	17	141	14.57%
Engineering Spaces	29	24	19	25	10	107	11.05%
Habitability Spaces	21	16	9	21	6	73	7.54%
Aviation Spaces	6	9	22	21	12	70	7.23%
Weapons Spaces	11	10	6	5	3	35	3.62%
Pier	1	8	6	12	7	34	3.51%
Other	17	14	10	5	5	51	5.27%
Totals	203	179	173	260	153	968	100.00%

Table 3. Shipboard Location of Back Injury Mishap by FY

Action	94	95	96	97	98	Totals	Percent
Handling Material Stores	74	56	51	83	43	307	31.71%
Walking/Stepping	43	41	32	51	34	201	20.76%
Equip. Installation/Removal	14	23	18	38	21	114	11.78%
Housekeeping	10	10	13	8	5	46	4.75%
Handling Lines	10	10	5	4	7	36	3.72%
Other	52	39	54	76	43	264	27.27%
Total	203	179	173	260	153	968	100.00%

Table 4. Job Action During Back Injury Mishap by FY

Classification of injury mechanism entails an analysis of the injury causing action as reported in the SCMs. Table 5 provides a tabulation of back injury mishaps according to injury mechanism by year. Of the 968 injuries, the majority are attributed to an overexertion action 556 (57%). Falls/jumps from elevation accounted for 193 (20%) of the injuries while fall/jumps from the same level accounted for another 126 (13%). The remaining 93 (10%) were attributed to various other injury causing actions.

Injury Mechanism	94	95	96	97	98	Totals	Percent
Overexertion	109	99	93	169	86	556	57.44%
Fall/Jump from Elevation	48	42	38	35	30	193	19.94%
Fall from Same Level	19	18	24	42	23	126	13.02%
Other	27	20	18	14	14	93	9.61%
Total	203	179	173	260	153	968	100.00%

Table 5. Back Injury Mishaps by Injury Mechanism per FY

In addition to examining the areas and actions most often associated with back injuries, an analysis of the objects, equipment, vehicles or hardware involved in each mishap may provide useful insight. Of the back injury mishaps reviewed for this study, 255 (26.34%) involved objects being lifted/carried/moved, 187 (19.32%) involved ladders (stairs), 150 (15.50%) involved boxes/barrels/containers, 69 (7.13%) involved the deck/deck covering, 35 (3.62%) involved furniture/fixtures/furnishings, 27 (2.79%) involved lines and the remaining 245 (25.31%) involved other objects in 50 different categories. The majority of injuries were associated with movement of objects, ladders (stairs) or containers. Table 6 provides a detailed breakdown of the objects, equipment or hardware involved in back injury mishaps.

Objects Involved	94	95	96	97	98	Totals	Percent
Object Lifted/Carried/Moved	38	37	46	86	48	255	26.34%
Ladders	45	35	32	49	26	187	19.32%
Box/Barrel/Container	32	38	19	39	22	150	15.50%
Deck/Deck Covering	12	11	11	22	13	69	7.13%
Furniture/Fixture/Furnishing	9	6	12	5	3	35	3.62%
Line	6	8	4	3	6	27	2.79%
Other (in 50 Categories)	61	44	49	56	35	245	25.31%
Total	203	179	173	260	153	968	100.00%

Table 6. Objects Involved in Back Injury Mishaps by FY

Table 7 provides a tabulation of back injury mishaps by rank to better identify the personnel most likely to receive such an injury. As is consistent with findings by Sciretta (1999, p. 40), E3's through E5's, who conduct the majority of the maintenance and manual lifting tasks onboard ships, account for most of the mishaps (66.84%). As displayed on Figure 7, the histogram of back injury mishaps appears highest on E4's (mode) with a slight skew to the lower ranks indicating that junior personnel are more likely to be undertaking labor intense tasks. As is consistent with Figure 7, the average age of personnel suffering from a reported back injury is 25 years or approximately the average age of a Navy E4.

Rate/Rank	94	95	96	97	98	Totals	Percent
E1	5	13	10	16	13	57	5.89%
E2	29	26	16	25	13	109	11.26%
E3	49	39	38	66	38	230	23.76%
E4	50	43	50	79	42	264	27.27%
E5	36	29	34	39	15	153	15.81%
E6	25	22	19	22	23	111	11.47%
E7	5	3	4	5	6	23	2.38%
E8-O4	4	4	2	8	3	21	2.17%
Totals	203	179	173	260	153	968	100.00%

Table 7. Back Injury Mishaps by Rank per FY

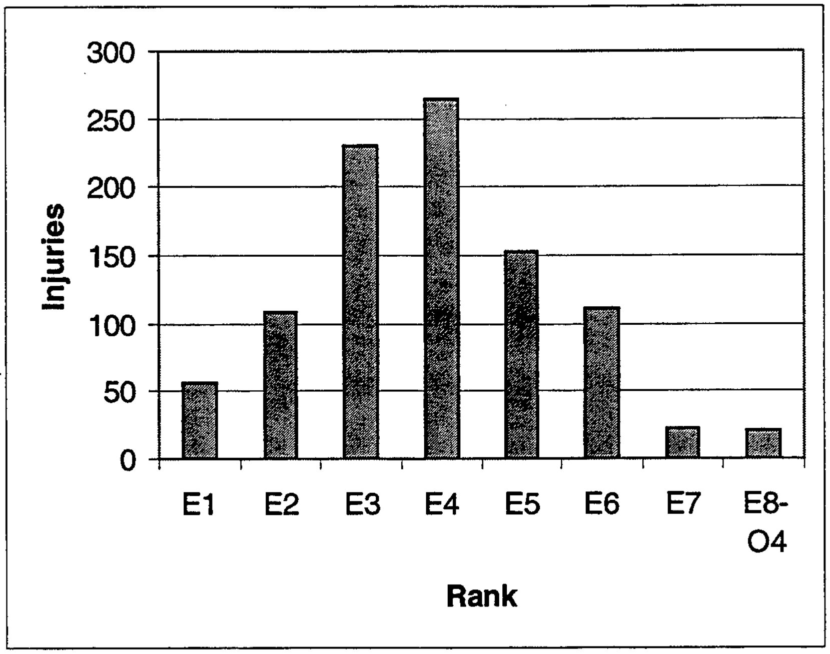


Figure 7. Histogram of Back Injury Mishaps by Rank

When sorted by sex, back injury mishaps do not appear to be any more likely to afflict either sex. Table 8 provides a breakdown of back injury mishaps by sex. During the period of study, females made up approximately 12.4 % of the enlisted population, yet suffered 12.81% of the reported back injuries. Males made up 87.6% of the population and suffered 87.19% of the injuries. This outcome calls into question findings by Magora (1977, p. 465) and Hoiberg (1980) that sex is related to accident or injury frequency.

Sex	94	95	96	97	98	Totals	Percent
Male	171	153	161	230	129	844	87.19%
Female	32	26	12	30	24	124	12.81%
Totals	203	179	173	260	153	968	100.00%

Table 8. Back Injury Mishaps by Sex per FY

Once an injury does occur, most were diagnosed as strains 754 (77.89%) with the remaining 214 (22.11%) being diagnosed as sprains, contusions or other. In addition, these injuries are classified by injury type. For the purposes of this study injuries are

broken down into: First Aid, Minor, Major, Permanent Partial Disability, Permanent Total Disability, and Fatal Injuries. "First Aid Injuries" are those injuries for which the victim requires minimal treatment and experiences no time away from work and account for 530 (54.75%) of the mishaps. "Minor Injuries" are those which result in at least one but not more than four lost workdays not including the day of injury and account for 303 (31.03%) of the mishaps. "Major Injuries" are those which do not result in death or permanent disability but which result in five or more lost workdays not including the day of injury and account for 130 (13.43%) of the mishaps. "Permanent Partial Disability" is an injury which does not result in death or permanent total disability but, in the opinion of competent medical authority, results in permanent impairment or loss of any part of the body and account for 3 (0.31%) of the mishaps. "Permanent Total Disability" is a nonfatal injury that, in the opinion of competent medical authority, permanently and totally incapacitates a person to the extent that he/she cannot follow any gainful occupation. Together, fatalities and permanent total disability injuries account for 2 (0.2%) of the mishaps. Tables 9 and 10 provide a detailed tabulation of diagnosis and injury type for back injury mishaps.

Diagnosis	94	95	96	97	98	Totals	Percent
Strain	122	142	134	233	123	754	77.89%
Sprain	51	3	2	0	4	60	6.20%
Contusion	15	24	18	15	10	82	8.47%
Other	15	10	19	12	16	72	7.44%
Total	203	179	173	260	153	968	100.00%

Table 9. Diagnosis of Back Injury Mishaps by FY

Injury Type	94	95	96	97	98	Total	Percent
First Aid Injury	103	104	86	150	87	530	54.75%
Minor Injury	63	52	58	83	47	303	31.30%
Major Injury	35	23	27	26	19	130	13.43%
Permanent Partial Disability	1	0	1	1	0	3	0.31%
Permanent Total Disability	0	0	1	0	0	1	0.10%
Fatal Injury	1	0	0	0	0	1	0.10%
Total	203	179	173	260	153	968	100.00%

Table 10. Back Injury Mishaps by Injury Type per FY

Back injury mishap costs are calculated by determining the total days hospitalized, days lost and days of restricted work activity and multiplying each by the DOD daily standard cost for each type of day. Table 11 provides a tabulation of each along with the number of fatalities, permanent total disabilities and permanent partial disabilities of enlisted personnel by year. The tabulation of injury costs are as follows: 737 back injury mishaps accounted for 5,753 days of restricted work activity, 3,283 lost work days, and 611 days of hospitalization. Three mishaps generated permanent partial disability, one mishap created permanent total disability and one mishap resulted in a fatality. The remaining 231 back injury mishaps involve no lost time injury cases. The DOD cost standard table is provided in Appendix D with a justification of cost estimation techniques used for analysis in Table 11.

CY98$	94	95	96	97	98	Totals	Rate	Cost
Restricted Activity Days	1246	954	980	1372	1201	5753	$249	$1,432,497
Lost Work Days	744	653	883	595	408	3283	$496	$1,628,368
Hospitalized Days	121	144	158	102	86	611	$617	$376,987
Permanent Partial Disability	1	0	1	1	0	3	$152,177	$456,531
Permanent Total Disability	0	0	1	0	0	1	$661,638	$661,638
Fatality	1	0	0	0	0	1	$165,410	$165,410
No Lost Time Injuries	78	52	29	51	21	231	$159	$36,729
Total Injury Cost	$1,083,924	$658,550	$1,597,900	$859,968	$557,818			$4,758,160

Table 11. Back Injury Mishap Severity and Costs by FY

C. MODEL FORMULATION

1. Arrival Process Formulation

To measure the contributions of broad occupational categories to the overall arrival process of back injuries, the data set was sorted into eight job families. Job families were developed in accordance with the NAVPERSCOM organization of enlisted personnel and were grouped by specialty rating provided in Table 1 as: Engineering, Aviation, Deck, Supply, Technical and Other (to include the Medical, Administrative, and Electronic Warfare specialties). In addition, the job families of Seaman and Fireman were added to account for non-specialized personnel. Naval Officers and Marine Corps personnel were grouped in the "Other" job family for arrival process formulation. Table 12 displays the number of back injuries experienced by personnel in these job families by year.

Job Family	94	95	96	97	98	Total	Percent
Engineering	75	42	56	56	29	258	26.65%
Aviation	19	24	38	59	37	177	18.29%
Technical	29	32	27	28	24	140	14.46%
Seaman	25	30	14	34	19	122	12.60%
Supply	19	15	17	32	17	100	10.33%
Deck	15	11	6	18	13	63	6.51%
Other	12	12	9	20	9	62	6.40%
Fireman	9	13	6	13	5	46	4.75%
Totals	203	179	173	260	153	968	100.00%

Table 12. Back Injury Mishaps by Job Family per FY

The job family categorization is based on the assumption that personnel in the same military specialties performed the same types of tasks across all operational platforms (ships and submarines). Therefore, a model that could depict the arrival of back injuries based on the similarity of personnel activities could identify and measure those personnel most at risk of injury. The U.S. Navy could target intervention strategies on those personnel and measure results in an attempt to determine the effect on the overall arrival process. A pooled renewal process comprised of the eight job families previously described is chosen to model the back injury arrival process. Figure 8 illustrates the arrival process of the first four job families projected onto the arrival process of the Navy as a whole where $N_k(t)$ represents the number of back injuries that occur in $(0, t]$ for each job family k.

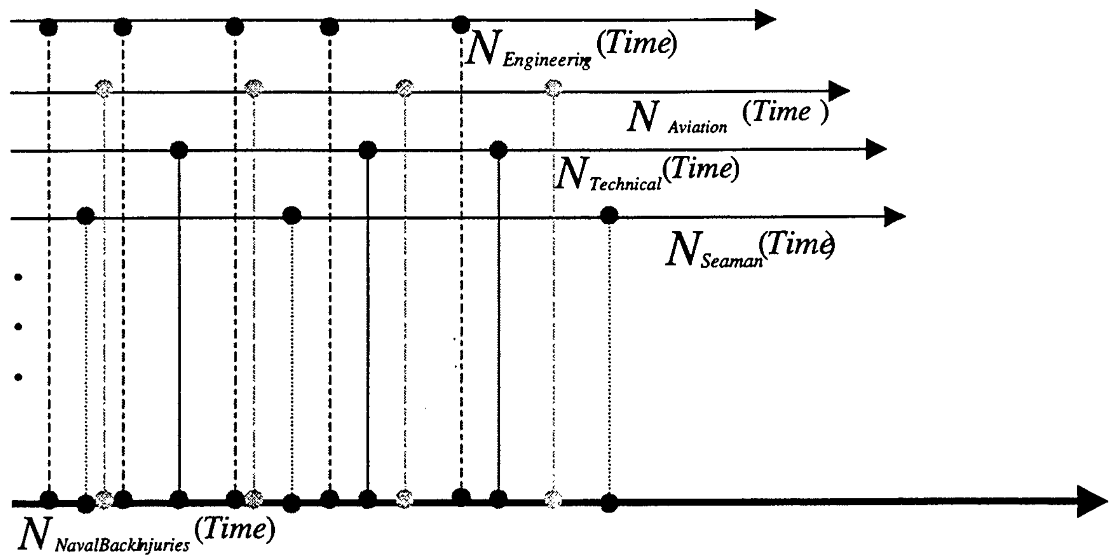


Figure 8. Pooled Back Injury Mishap Arrival Process of First Four Job Families

From the mishap data, the study computes the inter-event times for each job family's back injuries. An examination of the histograms of inter-event times for each job family indicates that the inter-event times can be modeled by exponential distributions. Figure 9 depicts the histogram of inter-injury times for the Engineering job family.

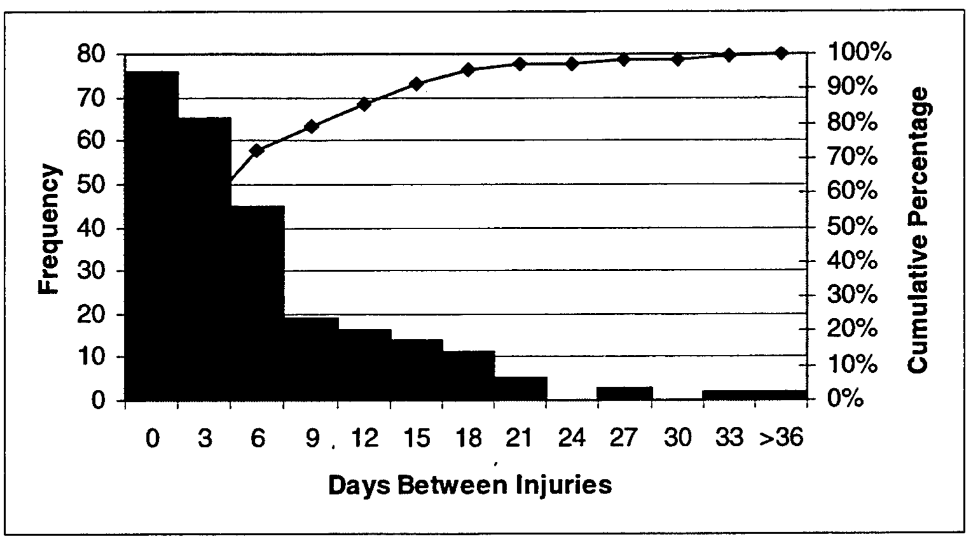


Figure 9. Histogram of Inter-injury Time for the Engineering Job Family

The Kolmogorov-Smirnov Test was applied to each job family to determine the suitability of the exponential distribution to describe the respective inter-injury arrival distributions. For all job families, except Engineering, there was not enough evidence to reject, at a 5% level of significance, the null hypothesis: inter-arrival times for all job families follow an exponential distribution. The summary statistics and p-values of the Kolomogorov-Smirnov (KS) tests are displayed in Table 13. For each job family, note the closeness between the mean and standard deviation which is characteristic of the exponential distribution where the mean and standard deviation are equal.

Job Family	Mishap Count	Mean Inter-Injury Time (in Days)	Std. Dev. Of Inter-Injury Times (in Days)	Kolmogorov-Smirnov Test p-value
Engineering	258	7.00	7.72	.0014
Aviation	177	10.21	11.22	.0918
Technical	140	13.02	12.22	.5132
Seaman	122	14.61	15.71	.5202
Supply	100	18.00	19.88	.4678
Deck	63	28.63	34.91	.4361
Other	62	28.42	31.19	.3781
Fireman	46	39.35	40.18	.9228

Table 13. Summary Statistics and Goodness of Fit Test Results for Each Job Family

Because Engineering had the lowest p-value in the KS test, a visual comparison of this job family to random numbers generated by the exponential distribution, with the same mean, helps to examine the hypothesis that these inter-injury times are exponentially distributed. The quantile-quantile plot displayed in Figure 10 provides a visual comparison that indicates the inter-arrival times of Engineering back injuries may indeed be modeled by the exponential distribution. Additionally, the Engineering job family had the highest number of back injuries (n = 258) when compared to the other job families listed on Table 12. The high number of observations in this job family creates

high power in the KS test and may allow that test to reject the null hypothesis even when the truth differs from the null only insignificantly. With this behavior noted, model development continued under the premise that inter-injury times of personnel in the Engineering job family follow an exponential distribution with a mean of 7.00 days.

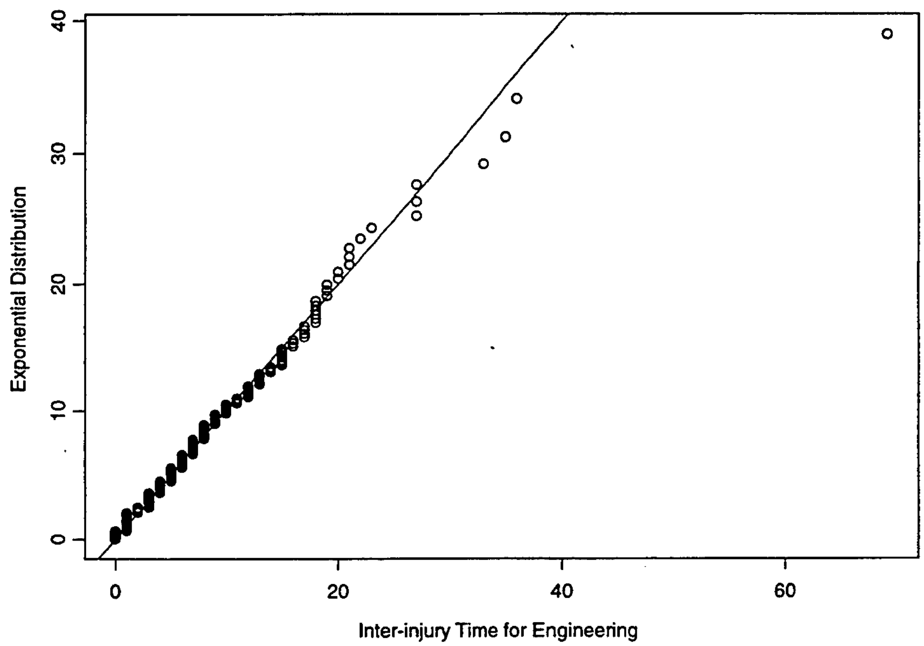


Figure 10. Quantile-Quantile Exponential Plot

Further, modeling the arrival process of back injuries as a pooled renewal process using the empirical means listed in Table 11 allows for aggregation to estimate the average inter-injury time for the entire Navy as:

$$\mu_{NavalBackInjuries} = \frac{1}{\frac{1}{\mu_{Eng.}} + \frac{1}{\mu_{Avia.}} + \frac{1}{\mu_{Tech.}} + \frac{1}{\mu_{SN}} + \frac{1}{\mu_{Supp.}} + \frac{1}{\mu_{Deck.}} + \frac{1}{\mu_{Other}} + \frac{1}{\mu_{FN}}}$$

where μ_k represents the empirical mean for job family k.

Using the formula above, the mean inter-injury time for back injuries in the entire Navy is 1.86 days. Thus, the random variable representing days between naval back injuries could be expressed as an exponential random variable with mean 1.86.

2. Days Hospitalized, Days Lost and Days of Restricted Activity

Once a back injury takes place, an evaluation by a qualified medical professional is performed to determine the severity of the injury and to prescribe a treatment regimen. The injured person may be medically evacuated to the nearest hospital, placed sick-in-quarters, placed on limited duty or returned to full duty. The NSC classifies "days lost" as the time personnel spend in a sick-in-quarters status where they are completely removed from the work-center as a result of the mishap. "Days restricted" is classified as the time personnel, who are returned to duty, spend in a limited duty status were they are unable to perform certain physical tasks. "Days hospitalized" are classified as the time spent as an inpatient in a medical facility. Tables 14, 15 and 16 provide a breakdown of the number of days lost, days of restricted activity and days of hospitalization for each job family by year. In comparing Table 12 with Tables 14, 15, and 16, it appears that as the number of injuries in one job family change each year, so to do the corresponding number of days lost, days restricted, and days of hospitalization.

Job Family	94	95	96	97	98	Total	Percent
Engineering	308	202	162	132	92	896	27.29%
Aviation	36	72	153	80	34	375	11.42%
Technical	103	149	298	28	67	645	19.65%
Seaman	70	25	24	65	3	187	5.70%
Supply	38	21	60	26	68	213	6.49%
Deck	54	76	32	114	119	395	12.03%
Other	114	99	139	105	21	478	14.56%
Fireman	21	9	15	45	4	94	2.86%
Totals	744	653	883	595	408	3283	100.00%

Table 14. Days Lost Due to Back Injury Mishaps per FY

Job Family	94	95	96	97	98	Total	Percent
Engineering	388	463	213	291	411	1766	30.70%
Aviation	36	109	174	279	208	806	14.01%
Technical	41	121	150	134	205	651	11.32%
Seaman	273	94	65	153	41	626	10.88%
Supply	62	40	52	122	100	376	6.54%
Deck	42	36	81	54	155	368	6.40%
Other	364	50	214	303	44	975	16.95%
Fireman	40	41	31	36	37	185	3.22%
Totals	1246	954	980	1372	1201	5753	100.00%

Table 15. Days of Restricted Activity Due to Back Injury Mishaps per FY

Job Family	94	95	96	97	98	Total	Percent
Engineering	29	54	37	11	5	136	22.26%
Aviation	5	3	40	26	7	81	13.26%
Deck	5	31	3	14	43	96	15.71%
Supply	3	4	2	5	23	37	6.06%
Technical	12	9	48	5	5	79	12.93%
Seaman	8	10	19	4	1	42	6.87%
Other	54	32	6	37	1	130	21.28%
Fireman	5	1	3	0	1	10	1.64%
Totals	121	144	158	102	86	611	100.00%

Table 16. Days Hospitalized Due to Back Injury Mishaps per FY

Numerous attempts to identify a probability distribution(s) sufficiently reflective of the collected sample data for days lost, days restricted and hospitalization were unsuccessful. In situations were data has been collected from an unknown probability distribution, bootstrap replication, or re-sampling from an existing data set, has proven useful. According to Efron and Tibshirani (1993):

> In the real world, the unknown probability distribution F gives the data $x = (x_1, x_2, \ldots, x_n)$ by random sampling. In the bootstrap world, the empirical distribution F^* gives bootstrap samples $x^* = (x_{1*}, x_{2*}, \ldots, x_{n*})$ by ramdom sampling from existing data, from which we calculate bootstrap replications of the statistic of interest. The big advantage of the bootstrap world is that we can calculate as many replications as we want, or at least as many as we can computationally afford. This allows us to do probabilistic calculations directly by using observations of F^* to estimate statistics of interest in the unknown population F. (p.87)

Let $L_k(n)$ be the number of days lost, $R_k(n)$ be the number of days restricted and $H_k(n)$ be the number of days hospitalized resulting from n injuries for each job family k, where n is the result of $N_k(t)$ or the number of back injuries occurring in $(0,t]$ that have exponentially distributed inter-injury times. Once an injury occurs, a bootstrap sample from the sorted FY94 – FY98 data set for job family k is drawn to determine the days lost, days restricted, and days hospitalized for that injury. Using the bootstrap method, $L_k(n)$, $R_k(n)$, and $H_k(n)$ can be determined by re-sampling n times with replacement from previous observations of the number of days lost, days of restricted work activity, and day hospitalized where each previous observation has an equal probability of being drawn as follows:

$$L_k(n) = \sum_{i=1}^{n} \textit{Sample Back Injury}_i \textit{ Days Lost}$$

$$R_k(n) = \sum_{i=1}^{n} \textit{Sample Back Injury}_i \textit{ Days Restricted}$$

$$H_k(n) = \sum_{i=1}^{n} \textit{Sample Back Injury}_i \textit{ Days Hospitalized}$$

for each job family k.

To develop an empirical distribution of $L_k(n)$, $R_k(n)$, and $H_k(n)$, data for each injury i above is generated by re-sampling from previous back injury mishaps sorted by days lost days restricted and days hospitalized for each job family k.

D. MODEL SIMULATION

In this model, the number of days between one injury and the next is an exponential random variable with mean μ_k as listed on Table 12 for each job family k. In order to simulate a back injury event, this exponential random variable is generated to determine the number of days to the next injury. The injury event triggers a bootstrap sample, as described above, to determine the days lost, days restricted, and days

hospitalized. The injury cost is simply the number of days lost, days restricted, and days hospitalized multiplied by the respective daily rate (Table 11). The results of the sample are recorded, and the next exponential random exponential random variable is drawn to determine the next point in time for the next sample. Figure 11 provides a graphic display of the simulation event generation.

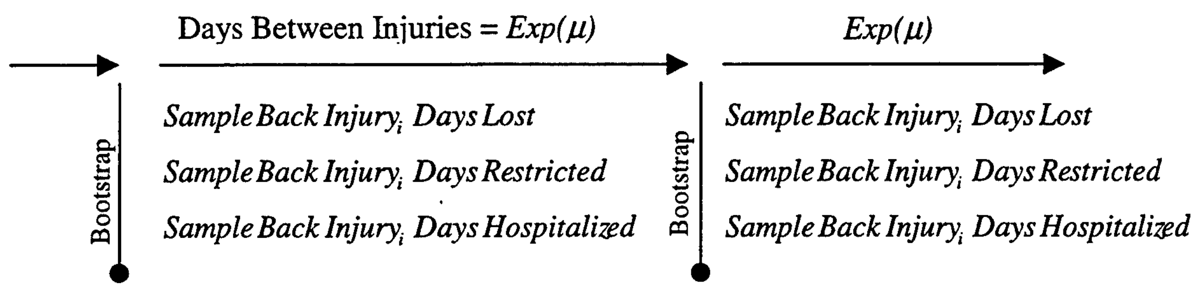
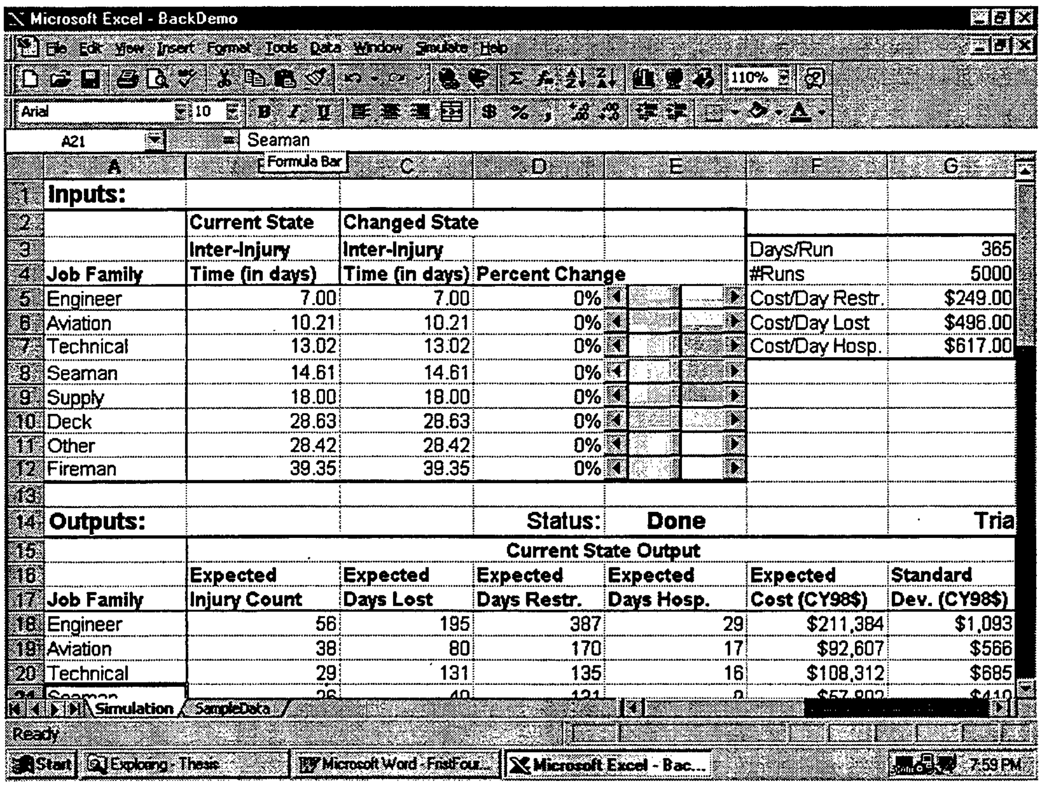


Figure 11. Back Injury Event Simulation

Determining the effect of proposed intervention strategies requires that the simulation compare a current state, where inter-injury times are distributed exponential *(μ)*, with a stated changed from an intervention strategy where the inter-injury times are now exponential *(μ*)*. The changed state will continue to resample from the same injury data for days lost, days restricted, and days hospitalized, but at a different rate from the current state. When the results of two simulations are compared, occupational health and safety personnel can measure the expected impact in days lost, days restricted, days hospitalized and cost from an intervention that has reduced back injury occurrence.

Microsoft Excel 97 (1997) was used to build the input section for the mean inter-injury times of each job family. Slide bar controls for the changed state mean inter-injury times were linked to the corresponding percentage change in the current state. The two states are displayed side by side in Figure 12 for each job family. In addition, the cost per day lost, day restricted and day hospitalized can be changed to measure the expected

impact on total costs. The days per run (days/run) input section allows the user to vary the simulation time in days, so for instance, simulations of 5 years (1825 days) in length could be run rather than single year periods. By increasing the number of runs, the user decreases variance and increases the confidence of the expected results at the expense of longer run times for the simulation. Indices of days lost, days restricted, and days hospitalized, sorted by job family, for all FY94 –FY98 back injuries are stored in a separate worksheet for bootstrap sampling.



	A	B	C	D	E	F	G
1	**Inputs:**						
2		**Current State**	**Changed State**				
3		**Inter-Injury**	**Inter-Injury**			Days/Run	365
4	**Job Family**	**Time (in days)**	**Time (in days)**	**Percent Change**		#Runs	5000
5	Engineer	7.00	7.00	0%		Cost/Day Restr.	$249.00
6	Aviation	10.21	10.21	0%		Cost/Day Lost	$496.00
7	Technical	13.02	13.02	0%		Cost/Day Hosp.	$617.00
8	Seaman	14.61	14.61	0%			
9	Supply	18.00	18.00	0%			
10	Deck	28.63	28.63	0%			
11	Other	28.42	28.42	0%			
12	Fireman	39.35	39.35	0%			
13							
14	**Outputs:**			**Status:**	**Done**		**Tria**
15				**Current State Output**			
16		**Expected**	**Expected**	**Expected**	**Expected**	**Expected**	**Standard**
17	**Job Family**	**Injury Count**	**Days Lost**	**Days Restr.**	**Days Hosp.**	**Cost (CY98$)**	**Dev. (CY98$)**
18	Engineer	56	195	387	29	$211,384	$1,093
19	Aviation	38	80	170	17	$92,607	$566
20	Technical	29	131	135	16	$108,312	$685

Figure 12. Current State Input Section with Slide Bar Controls for Changed State

The SIM.xla add-in developed by Savage (1998) in Insight.xla provides the gen_Exponential(μ) function that generates numbers from the exponential distribution with parameter μ. By linking the input cells of Figure 12 to calls on the gen_Exponential(μ) function, the inter-injury times of the back injury process for the

current and changed states of each job family can be simulated. In addition, Savage (1998) provides a gen_Resample(Index) function that randomly selects one element from the Index parameter which can be used to bootstrap from the sorted indices of days lost, days restricted and days hospitalized to determine the cost of each injury. Appendix D displays the Microsoft Visual Basic code for the BackSimulation macro created to simulate the back injury process for all job families.

Once the simulation has completed all assigned runs from the input section, the output section displays the expected number of days lost, days restricted, and days hospitalized along with the expected cost and standard deviation of cost for the current and changed state of each job family. Totals of the deviations between states allow for measurement of the impact on the total process of changes in one or more of individual job family arrival processes. Figure 13 displays a portion of the output section from the BackSimulation macro along with graphical comparison of total costs between current and changed states for each job family.

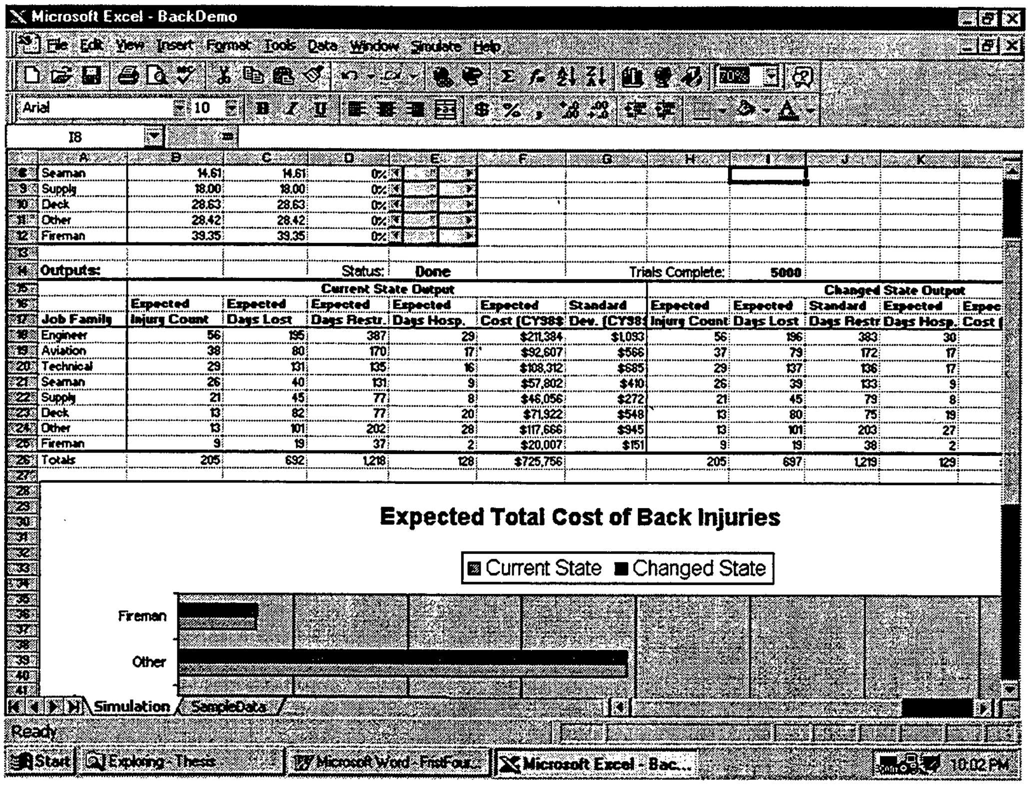


Figure 13. Output Section of BackSimulation Macro

E. MODEL APPLICATION

The BackSimulation model provides decision-makers with a tool to measure the expected outcome of an intervention strategy before implementation. The variable controls allow the user to tailor the effect of proposed changes on the back injury arrival process for each job family and measure the resultant outcome in terms of injuries, days lost, days restricted, days hospitalized and cost. The following scenarios are hypothetical examples of situations where the BackSimulation model will provide the decision-maker with a tool to measure the outcome of proposed intervention strategies. The examples below are simulated 5000 times for periods of one year in determining the results provided for each.

1. Measuring Navy-Wide Interventions

Suppose Occupational Health Professionals would like to determine the savings in lost days, days of restricted activity, days hospitalized and cost to the entire Navy of a new comprehensive physical wellness program which contains back injury prevention education and physical training. Occupational health studies of industries, which have under taken similar programs, suggest that the new program will reduce back injuries by 30 percent per year. Figure 14 displays the expected results of such an intervention. The new program is expected to prevent 49 (205-156) injuries and save $174,000 (CY98$) per year in back injury costs.

Outputs:			Status:	Done				Trials Complete:	5000				
	Current State Output						Changed State Output						
	Expected	Expected	Expected	Expected	Expected	Standard	Expected	Expected	Standard	Expected	Expected	Expected	Cost Difference
Job Family	Injury Count	Days Lost	Days Restr.	Days Hosp.	Cost (CY98$)	Dev. (CY98$)	Injury Count	Days Lost	Days Restr.	Days Hosp.	Cost (CY98$)	Dev. (CY98$)	Between States
Engineer	56	196	390	30	$211,978	$1,071	42	146	293	22	$158,818	$938	$53,160
Aviation	38	79	171	17	$91,847	$668	29	61	130	13	$70,603	$490	$21,244
Technical	29	134	135	17	$110,088	$707	22	102	104	12	$84,248	$629	$25,839
Seaman	26	39	132	9	$57,751	$424	20	30	101	7	$44,155	$353	$13,597
Supply	21	45	79	8	$46,467	$274	16	34	59	6	$35,043	$233	$11,425
Deck	13	81	77	20	$71,111	$546	10	63	57	15	$54,756	$481	$16,356
Other	13	102	209	27	$119,362	$940	10	77	162	21	$91,485	$825	$27,877
Fireman	9	19	38	2	$20,193	$153	7	15	29	2	$15,442	$133	$4,750
Totals	205	692	1,230	128	$728,798		156	527	936	97	$554,549	Difference	$174,248

Figure 14. BackSimulation Output for 30% Navy-Wide Reduction

2. Measuring Multiple Job Family Interventions

Suppose designers of the new DD-21 have determined that changes to the layout and task performance in the engineering spaces will reduce the occurrence of back injuries by 40 percent per year. The enlisted community manager for engineering and hull specialties would like to know the expected impact on the Engineering and Fireman job families while holding the other job families constant if these changes were implemented across the fleet. Figure 15 displays the expected results. The new design is expected to prevent 19 injuries and save $67,000 (CY98$) per year in back injury costs.

Outputs:			Status:	Done			Trials Complete:	5000					
	Current State Output						Changed State Output						
	Expected	Expected	Expected	Expected	Expected	Standard	Expected	Expected	Standard	Expected	Expected	Expected	Cost Difference
Job Family	Injury Count	Days Lost	Days Restr.	Days Hosp.	Cost (CY98$)	Dev. (CY98$)	Injury Count	Days Lost	Days Restr.	Days Hosp.	Cost (CY98$)	Dev. (CY98$)	Between States
Engineer	56	195	385	30	$210,868	$1,105	39	137	268	21	$147,370	$881	$63,498
Aviation	38	80	171	17	$92,904	$564	38	80	169	17	$92,556	$574	$348
Technical	29	133	135	16	$109,633	$709	29	136	135	16	$111,116	$727	-$1,482
Seaman	26	40	132	9	$58,533	$412	26	40	132	9	$58,150	$415	$383
Supply	21	45	79	8	$46,692	$276	21	44	78	8	$46,059	$273	$634
Deck	13	81	78	20	$71,759	$554	13	82	76	20	$71,599	$553	$160
Other	13	100	203	28	$117,282	$909	13	102	208	28	$119,788	$941	-$2,507
Fireman	9	19	38	2	$20,193	$152	7	13	27	1	$14,108	$125	$6,085
Totals	205	693	1,221	130	$727,864		166	633	1,094	120	$660,746	Difference	$67,119

Figure 15. BackSimulation Output for 40% Reduction in Engineering and Fireman

3. Measuring Single Job Family Interventions

Suppose NAVOSH personnel have determined that back injuries to personnel in aviation subspecialties can be reduced by 50 percent through improved screening. The NAVSAFECEN would like to know how many injuries would be avoided by this intervention. Figure 16 displays the BackSimulation results. Improved screening is expected to reduce the number of back injuries by 13 per year.

Outputs:			Status:	Done			Trials Complete:	5000					
	Current State Output						Changed State Output						
	Expected	Expected	Expected	Expected	Expected	Standard	Expected	Expected	Standard	Expected	Expected	Expected	Cost Difference
Job Family	Injury Count	Days Lost	Days Restr.	Days Hosp.	Cost (CY98$)	Dev. (CY98$)	Injury Count	Days Lost	Days Restr.	Days Hosp.	Cost (CY98$)	Dev. (CY98$)	Between States
Engineer	56	196	385	30	$211,170	$1,091	56	196	386	29	$211,121	$1,089	$49
Aviation	38	80	172	17	$93,461	$575	25	51	112	11	$60,170	$450	$33,291
Technical	29	134	136	16	$110,212	$708	29	133	136	16	$109,359	$709	$853
Seaman	26	40	134	9	$58,840	$412	26	40	131	9	$57,979	$407	$862
Supply	21	44	78	8	$46,153	$275	21	44	78	8	$46,088	$271	$65
Deck	13	82	76	20	$71,696	$555	13	81	75	20	$70,903	$546	$793
Other	13	100	206	28	$118,176	$929	13	100	206	27	$117,829	$925	$347
Fireman	9	19	38	2	$20,265	$153	9	19	38	2	$20,132	$153	$133
Totals	205	695	1,225	130	$729,973		192	664	1,160	122	$693,580	Difference	$36,393

Figure 16. BackSimulation Output for 50% Reduction in Aviation

In last two simulation examples above, the random nature of the individual simulation runs creates minor differences in the results of job families with unchanged arrival rates. The comparatively large differences in the results of job families with changed arrival rates are also subject to this randomness and may vary slightly between simulation runs. The intent of the simulation is to measure the expected results between changed states while recognizing the minor variability in the model as whole.

V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The physically demanding work aboard U.S. Navy vessels creates an environment replete with risks of personnel injury. Required actions such as heavy lifting, moving in confined spaces, or traveling over uneven surfaces are part of the daily work routine for many Naval occupations that lead to back injury. Currently, 76% of Naval personnel who experience back injuries incur lost work time, work in a restricted duty status, and/or hospitalization. From FY94 to FY98, the Naval Safety Center received 968 Special Case Mishap reports of personnel back injury accidents. Personnel back injury accidents are analyzed for common patterns of causative factors and outcomes as well as Human Factors involvement. Subsequently, models representing mishap events are developed. From the models, simulations are run to assess the effectiveness of interventions at reducing injuries, days lost, days restricted, and days hospitalized.

Categorical data analysis of mishap events describes many important features such as severity, ship type, onboard location, job action, injury mechanism and objects involved in back injuries. While one mishap resulted in a fatality, one in permanent total disability and three in the permanent partial disability of the victim, most mishaps (99.48%) are Class "C" or less in severity. Aircraft Carriers and Auxiliaries (oilers, ammunition ships and repair ships) accounted for 30% and 26% of the back injuries respectively. Mishaps occur most frequently in the deck (47%), supply (15%), and engineering (11%) spaces. Injured personnel are most often handling material stores (32%), walking/stepping (21%), or installing/removing equipment (12%) at the time of injury. The E-3, E-4 and E-5 rates are typically performing such activities and account

for most back injury mishaps (67%). Gender was not found to materially influence back injury risk because enlisted women make up approximately 12.4% of the active duty population and account for 12.8% of the back injury mishaps. The injury mechanisms most often attributed to back injuries are overexertion (57%) and to a lesser extent a fall/jump from elevation (20%), or fall from the same level (13%). The objects most frequently associated with injuries involve articles being lifted/carried/moved (26%), ladders (19%), or box/barrel/containers (16%).

Between 1994 and 1998, the U.S. Navy reported 968 back injury mishaps aboard ships and submarines which resulted in 3,283 lost work days, 5,753 days of restricted activity, and 611 days of hospitalization. To measure the contributions of broad occupational categories to a model of the back injury arrival process, the mishaps are sorted into eight job families in accordance with the NAVPERSCOM organization of enlisted personnel. A pooled renewal process of the job families projected onto the arrival process for the Navy as whole is developed to model the back injury arrival process. Inter-injury times for each job family are determined to be exponential random variables with mean μ_k for each job family k. Once an injury event occurs within the job family model, the bootstrap method is employed to determine the number of days lost, days restricted, and days hospitalized. Therefore, the cost of each injury event is determined by re-sampling from the 968 observations sorted by job family to generate the number of days lost, days restricted, and days hospitalized.

Finally, the model is used to develop a computer simulation of the entire back injury process. Simulations of the arrival process in a fixed state are compared with simulations of the arrival process changed due to an intervention strategy. The

differences between the two states are measured in terms of injuries, days lost, days restricted, days hospitalized and cost to measure the expected effect of interventions before implementation. Application of this simulation determined that a 30 percent Navy-wide reduction in back injuries would avoid 49 injuries, 165 days lost, 294 days of restricted activity, 31 days of hospitalization and save $174,000 (CY98$) annually.

B. CONCLUSIONS

This research indicates personnel aboard Carriers and Auxiliaries, performing material handling tasks, are most at risk of back injury due to overexertion. When considered according to population representation, gender is not found to materially influence back injury risk because enlisted women make up approximately 12.4 percent of the active duty population and account for 12.8 percent of the back injury mishaps. When grouped by job family according to related occupational specialties, the engineering, aviation, and technical groupings account for 59 percent of back injury mishaps.

Modeling back injury events as a pooled renewal process with exponential inter-injury times for each job family provides a sound representation of the mishap arrival process. For each injury event, the bootstrap method proves effective in modeling the number of days lost, days restricted, and days hospitalized used to determine cost. Once constructed, the model provides the means to simulate back injury events by job family.

Computer simulation of the back injury process over time allows for the measurement of intervention strategy effectiveness. Comparing expected outcomes of simulations where the arrival process is in a fixed state to simulations of the arrival

process in a changed state allows for the measurement of expected intervention effectiveness in terms of injuries, days lost, days restricted, days hospitalized and cost.

C. RECOMMENDATIONS

The high frequency of back injuries due to material handling tasks aboard Carriers and Auxiliaries indicates that these platforms should be targeted for future interventions. Prevention efforts should place renewed focus on physical training, back injury awareness education, and task re-design for specific work centers. In conjunction with effectiveness recommendations from occupational health specialists, the BackSimulation model should be used to estimate the effect of these intervention strategies in terms of injuries, days lost, days restricted, days hospitalized and cost. The expected outcome of various prevention programs applied to different target populations should be determined before scarce resources are applied.

Because the current reporting process lacks many of the elements necessary to model personnel injury causation, changes to the reporting process that would allow for efficient grouping of root causal factors are necessary. Any event model of the accident process is only as good as the reporting processes and reports from which it came. Hence, improvements to the reporting process will yield improved causation determination, analysis and modeling of injury events. Therefore, changes to OPNAVINST 5100.19C that provide systematic causation reporting are recommended to better understand root causation of injuries.

Not all categories of personnel injury mishaps have been explored. Injuries from toxic substance exposure contribute significantly to the total number of mishaps occurring annually aboard Naval ships and submarines. This study shows that mishap

victims can be aggregated into job families for event modeling and simulation. Future intervention strategies can then be evaluated to determine their expected effectiveness in terms of days lost, days restricted, days hospitalized and cost.

APPENDIX A. SAMPLE MISHAP REPORT MESSAGE

ADMINISTRATIVE MESSAGE

ROUTINE

R 152005Z NOV 98 ZYB PSN 821940I24

FM USS DEYO

TO COMNAVSAFECEN NORFOLK VA//30/50/054//

INFO COMDESRON TWO

UNCLAS //N05102//

MSGID/GENADMIN/DEYO/SEP//

SUBJ/AFLOAT MISHAP REPORT (MR) (REPORT SYMBOL OPNAV 5102-6)//

REF/A/DOC/CNO/15MAY96//

AMPN/REF A IS OPNAVINST 5100.19C, NAVOSH PROGRAM MANUAL FOR FORCES AFLOAT. FOR OFFICIAL USE ONLY. THIS IS A GENERAL USE MISHAP REPORT TO BE USED ONLY FOR SAFETY PURPOSES AS DEFINED IN CHAPTER A6 OF REF A.//
POC/TRAMPENAU/LT/SAFETY OFFICER/INMARSAT: 871-151-7454//

RMKS/ALPHA:

1. UIC OF MISHAP COMMAND: 20836.
2. HULL NUMBER/SIDE NUMBER: DD-989.
3. TYPE OF MISHAP: BACK INJURY.
4. LOCAL TIME AND DATE OF MISHAP: 021030B NOV 98.
5. GEOGRAPHIC LOCATION: ADRIATIC SEA.
6. WEATHER CONDITIONS: CLEAR.
7. LOCATION WHERE MISHAP OCCURRED: MOUNT 21 AND 22.
8. SHIP'S OR CRAFT'S EVOLUTION AT THE TIME OF MISHAP: NATO OPERATIONS IN ADRIATIC SEA.
9. SEA STATE AND DIRECTION: SEA STATE 1 FROM 110T.
10. SHIP'S EMPLOYMENT: MEDITERRANEAN DEPLOYMENT 98-3.
11. PAYLOAD: N/A.
12. RISK ASSESSMENT CODE (RAC): N/A.

BRAVO:

1. EQUIPMENT DAMAGED OR DESTROYED BY MISHAP: NONE.
2. ESTIMATED COST TO REPAIR OR REPLACE DOD PROPERTY: N/A.
3. ESTIMATED COST OF NON-DOD PROPERTY DAMAGE: N/A.
4. NUMBER OF SCHEDULED OPERATING DAYS LOST: N/A.

CHARLIE:

1. NAME/SSN/AGE/SEX/RACE: Doe, John J./111-22-333/22 YRS/ MALE/HISPANIC.

2. RANK AND DESIGNATOR OR RATE AND NEC, JOB AND EMPLOYMENT STATUS: E-4/FC3/1147/ACTIVE DUTY USN.
3. DUTY STATUS: ON-DUTY.
4. SPECIFIC JOB OR ACTIVITY INDIVIDUAL ENGAGED IN AT TIME OF MISHAP: LOADING CIWS.
5. NUMBER OF MONTHS EXPERIENCE AT THE JOB OF ACTIVITY: 12 MONTHS.
6. MEDICAL DIAGNOSIS: BACK INJURY.
7. EXTENT OF INJURIES AND PROGNOSIS FOR DISABILITY: NO DISABILITY.
8. ESTIMATE OF LOST TIME:

A. TOTAL NUMBER OF DAYS AWAY FROM JOB (LOST WORK DAYS)/DAYS LOST BEFORE PERMANENT LOSS TO COMMAND: 0 DAYS/0 DAYS.

B. DAYS IN HOSPITAL OR SICK BAY: 0 DAYS.

C. DAYS OF LIGHT OR LIMITED DUTY: 0 DAYS.

DELTA: NARRATIVE:

1. CHAIN OF EVENTS LEADING UP TO, THROUGH AND SUBSEQUENT TO MISHAP: ON 02 NOVEMBER 98, AT APPROXIMATELY 1030 LOCAL, SVCMBR INJURED HIS BACK WHILE LIFTING A 76 LB AMMUNITION CAN WHILE LOADING A CIWS MOUNT. MEMBER WAS USING AN IMPROPER LIFTING TECHNIQUE. SHIP'S MEDICAL PERSONNEL EXAMINED SVCMBR AND DIAGNOSED A MINOR STRAIN WITH NO LONG-TERM EFFECTS.

2. RECOMMENDATIONS OR ACTION TAKEN TO PREVENT RECURRENCE: SVCMBR USED IMPROPER LIFTING TECHNIQUE, WHEN LIFTING AMMUNITION CAN. SVCMBR'S DIVISION HELD TRAINING ON PROPER LIFTING PROCEDURES. AMMUNITION HANDLING TEAMS ARE BRIEFED ON LIFTING TECHNIQUES DURING SAFETY BRIEFS PRIOR TO ALL AMMUNITION HANDLING OPERATIONS.//

BT
NNNN
RTD:000-000/COPIES:

APPENDIX B. SAMPLE SPECIAL CASE MISHAP REPORT DATA

FOR OFFICIAL USE ONLY NAVAL SAFETY CENTER RUN DATE 11/12/1998
JOB r0001 BACK INJURIES OCCURRING ON SHIPS AND SUBS: Page 1703
PGM ssp4106a 10/01/1993 - 09/30/1998 Request No. 1

EVENT DATA:
Event Serial: 186110 Date: 05/27/1995 Severity: C OPERATIONAL
DOD Mishap Catg: MARINE - NOT UNDERWAY MISHAP Time: 810 DAY

Event Location (Ship, Sub, Small Craft):
Body of Water:
Port or Strait: NORFOLK, VA
Lat: Degs Mins Secs Long: Degs Mins Secs

Cost Matrix:

Event Injury Cost:	$	750
Event DOD Property Cost:	$	0
Event NON-DOD Property Cost:	$	0
Total Event Cost:	$	750

Fatalities/Injuries Occurring in Event:

	Navy Mil	Navy Fed Civ	Other
Fatality (A,U,L)	0	0	0
Perm Total Dis (B)	0	0	0
Perm Partial Dis (C)	0	0	0
Major Injury (D)	0	0	0
Minor Injury (E)	1	0	0
First Aid (F)	0	0	0
No Injury (G)	0	0	0
Missing/Unknown (X)	0	0	0

Source Documents:
Source Type: NAVAL MESSAGE
Reference ID: 201803Z JUN 95 Date of Source: 06/20/1995

Accountable Activity Data:
Involved Activity: TOLEDO UIC:
N21807
Environment: SUBMARINE SSN 769

INVOLVED ACTIVITY DATA:
Accountable Activity Indicator: YES

Involved Activity: TOLEDO
UIC: N21807 SSN 769 Prototype Hull: 688
Parent/Tycom: COMMANDER SUBMARINE FORCE US ATLANTIC FLEET
Involved Acty: Vessel Type: SSN Prototype Hull: 688

Reporting Activity: TOLEDO
UIC: N21807 SSN 769 Prototype Hull: 688
Parent/Tycom: COMMANDER SUBMARINE FORCE US ATLANTIC FLEET
Reporting Acty: Vessel Type: SSN Prototype Hull: 688

Environment: SUBMARINE

Ship Status: MOORED (NOT IN SHIPYARD)
Evolution: UPKEEP/AVAILABILITY

Mishap Type: 1 HANDLING MATERIAL/EQUIPMENT
Mishap Type: 1 HANDLING MATERIAL/EQUIPMENT

Cost Matrix:
Number of Lost Operating Days for the Activity: 0

Activity Injury Cost	$	750
Activity DOD Property Damage	$	0
Activity NON-DOD Property Damage	$	0
Total Activity Cost	$	750

Fatalities/Injuries Occurring at the Involved Activity:

	Navy Mil	Navy Fed Civ	Other
Fatality (A,U,L)	0	0	0
Perm Total Dis (B)	0	0	0
Perm Partial Dis (C)	0	0	0
Major Injury (D)	0	0	0
Minor Injury (E)	1	0	0
First Aid (F)	0	0	0
No Injury (G)	0	0	0
Missing/Unknown (X)	0	0	0

INJURED PERSON DATA:
Pers Catg: ENLISTED NON-AIRCREW
Service Status: NAVY
ACTIVE
Rank/Rate: PO2 Rating: MM2 Paygrade: E05

Sex: M Age: 25 Duty Status: ON DUTY
Perm Duty Station: TOLEDO
UIC: N21807 SSN 769 Prototype Hull: 688
Parent/Tycom: COMMANDER SUBMARINE FORCE US ATLANTIC FLEET

Overall Injury: MINOR INJURY

Specific Injuries: (* denotes primary injury)
* Body Part: BACK (LUMBAR REGION)
* Locn: POSTERIOR
* Diagnosis: STRAIN

Osha Occupational Ill? OCCUPATIONAL INJURY

Cost Matrix:

Injury Cost	$ 750	
Number of Days Hospitalized		0
Number of Days Restricted Activity		0
Number of Lost Workdays		2

General Area: DECK SPACES
Specific Area: TRUNK Compt No:
Job Catg: WATCHSTANDER
Job/Action: HANDLING, MATERIAL/STORES
Experience with this Job/Action: Months
Hrs Awake Prior to Event:

Object Involved: OBJECT LIFTED/CARRIED/MOVED/DROPPED
Accident Type: OVEREXERTION

Injury Mishap Type: HANDLING MATERIAL/EQUIPMENT

Training Type: NO DATA

Chemical/Toxic Exposure Data: NO DATA

Drug Factors: NO DATA

Personnel Protective Equipment: NO DATA

General Cause Factors: PERSONNEL

Specific Personnel Cause Factors: (* denotes injured person injured himself)
* Cause Person Catg: WATCHSTANDER
Service Status: NAVY
ACTIVE
Rank/Rate: PO2 Rating: MM2 Paygrade: E05 Duty Status: ON DUTY
Job/Action: HANDLING, MATERIAL/STORES
Experience With This Job/Action: Months
What: FAILED TO USE PROPER LIFTING TECHNIQUES
Why: HASTE
Why: INSUFFICIENT EXPERIENCE/SKILL/TRAINING

Specific Material Cause Factors: NO DATA

Specific Environmental Cause Factors: NO DATA

Specific Procedural Cause Factors: NO DATA

DAMAGED EQUIPMENT DATA: NO DATA

NARRATIVES:
Brief Narrative:
AFTER PASSING APPROX. 50 BURN BAGS, MM2 EXPERIENCE LOWER BACK PAINS.

Lessons Learned Narrative: no lessons learned narrative available

Event Narrative:
AFTER PASSING APPROXIMATELY 50 BURN BAGS WEIGHING ABOUT 20 POUNDS EACH THROUGH THE FORWARD ESCAPE TRUNK ON 27 MAY 95, MM2 WENT TO STAND UPRIGHT EXPERIENCING LOWER BACK PAIN, STRAINING HIS BACK. CORRECTIVE ACTION/RECOMMENDATION: TRAINING HELD FOR ALL HANDS ON BACK INJURY PREVENTION.

APPENDIX C. DOD COST STANDARD TABLES AND COST ESTIMATION TECHNIQUES

Department of Defense (DOD) Instruction 6055.7, April 10, 1989, "Mishap Investigation, Reporting, and Recordkeeping" provides guidance for investigation, reporting, and recordkeeping on mishaps and occupational illnesses. Enclosure 5, Attachment 1 of this instruction provides the "Cost Standard Table" for DOD agencies to determine personnel injury costs (DOD, 1989). Table C1 provides a condensed version of this table applicable to U.S. military personnel.

CY89$	Submarine And/or Flying Officer	Other Officers	Enlisted Personnel, Cadets
Fatality	$1,100,000	$395,000	$125,000
(flight crew member)			$270,000
Permanent Total Disability	$1,300,000	$845,000	$500,000
Permanent Partial Disability	$210,000	$145,000	$115,000
Lost Time Case (per day)	$425	$425	$375
Days Hospitalized (per day)	$466	$466	$466
No Lost Time Case (per day)	$120	$120	$120

Table C1. DOD Cost Standard Table for Personnel Injury (CY89$)

Cost figures for table C1 were provided in Constant Year 1989 (CY89) dollars. For the purpose of this study, cost figures were converted to CY98 dollars to adjust for inflation and provide a more current estimate of personnel injury cost. The back injury mishap database contains data on mishaps from 1994 through 1998. Personnel injury cost figures for each year are calculated in CY98 dollars in order to provide a common Base Year for future year cost estimates. Inflation adjustments were made using MPN

Composite inflation indices provided by the Naval Center for Cost Analysis (NCAA, 1998). Table C2 provides the cost figures in CY98 dollars used for personnel injury cost estimation in this study. Cost for personnel injuries involving restricted activity days were calculated at half the cost of the lost time cases.

CY98$	Submarine and/or Flying Officer	Other Officers	Enlisted Personnel, Cadets
Fatality	$1,455,604	$522,694	$165,410
(flight crew member)			$357,285
Permanent Total Disability	$1,720,259	$1,118,169	$661,638
Permanent Partial Disability	$277,888	$191,875	$152,177
Lost Time Case (per day)	$562	$562	$496
Days Hospitalized (per day)	$617	$617	$617
No Lost Time Case (per day)	$159	$159	$159

Table C2. DOD Cost Standard Table for Personnel Injury (CY98$)

APPENDIX D. BACK SIMULATION MACRO

Below is the Visual Basic code used to simulate back injury process aboard U.S. Navy vessels.

```
Sub BackSimulation()

' Simulation of the back injury arrival process where the number of days
' between injuries is an exponential random variable with mean mu and mu1
' corresponding the job family being being simulated in a constant and changed
' state respectively.  Observations of days lost, days restricted and
' days hospitalized are generated by resampling from prior observations.
' Days Lost and Days Hospitalized are resampled from an index to ensure
' observations come from the same mishap.

' Initialize Loop Variables
Dim d, daysRes, daysLost, daysHosp, totalCost As Double
Dim maxTrials, maxDays, count, trial, index As Integer
maxTrials = [runs].Value
maxDays = [daysRun].Value

' Initialize Engineering Variables
Dim trialEng(), trialEng1() As Double
Dim trialDaysLostEng(), trialDaysRestEng(), trialDaysHospEng(), injCountEng() As Double
Dim trialDaysLostEng1(), trialDaysRestEng1(), trialDaysHospEng1(), injCountEng1() As Double
ReDim trialEng(1 To maxTrials), trialEng1(1 To maxTrials)
ReDim trialDaysLostEng(1 To maxTrials), trialDaysRestEng(1 To maxTrials), trialDaysHospEng(1 To
maxTrials), injCountEng(1 To maxTrials)
ReDim trialDaysLostEng1(1 To maxTrials), trialDaysRestEng1(1 To maxTrials), trialDaysHospEng1(1 To
maxTrials), injCountEng1(1 To maxTrials)

' Initialize Aviation Variables
Dim trialAv(), trialAv1() As Double
Dim trialDaysLostAv(), trialDaysRestAv(), trialDaysHospAv(), injCountAv() As Double
Dim trialDaysLostAv1(), trialDaysRestAv1(), trialDaysHospAv1(), injCountAv1() As Double
ReDim trialAv(1 To maxTrials), trialAv1(1 To maxTrials)
ReDim trialDaysLostAv(1 To maxTrials), trialDaysRestAv(1 To maxTrials), trialDaysHospAv(1 To
maxTrials), injCountAv(1 To maxTrials)
ReDim trialDaysLostAv1(1 To maxTrials), trialDaysRestAv1(1 To maxTrials), trialDaysHospAv1(1 To
maxTrials), injCountAv1(1 To maxTrials)

' Initialize Technical Variables
Dim trialTec(), trialTec1() As Double
Dim trialDaysLostTec(), trialDaysRestTec(), trialDaysHospTec(), injCountTec() As Double
Dim trialDaysLostTec1(), trialDaysRestTec1(), trialDaysHospTec1(), injCountTec1() As Double
ReDim trialTec(1 To maxTrials), trialTec1(1 To maxTrials)
ReDim trialDaysLostTec(1 To maxTrials), trialDaysRestTec(1 To maxTrials), trialDaysHospTec(1 To
maxTrials), injCountTec(1 To maxTrials)
ReDim trialDaysLostTec1(1 To maxTrials), trialDaysRestTec1(1 To maxTrials), trialDaysHospTec1(1 To
maxTrials), injCountTec1(1 To maxTrials)

' Initialize Seaman Variables
Dim trialSea(), trialSea1() As Double
Dim trialDaysLostSea(), trialDaysRestSea(), trialDaysHospSea(), injCountSea() As Double
Dim trialDaysLostSea1(), trialDaysRestSea1(), trialDaysHospSea1(), injCountSea1() As Double
ReDim trialSea(1 To maxTrials), trialSea1(1 To maxTrials)
ReDim trialDaysLostSea(1 To maxTrials), trialDaysRestSea(1 To maxTrials), trialDaysHospSea(1 To
maxTrials), injCountSea(1 To maxTrials)
ReDim trialDaysLostSea1(1 To maxTrials), trialDaysRestSea1(1 To maxTrials), trialDaysHospSea1(1 To
maxTrials), injCountSea1(1 To maxTrials)

' Initialize Supply Variables
Dim trialSup(), trialSup1() As Double
Dim trialDaysLostSup(), trialDaysRestSup(), trialDaysHospSup(), injCountSup() As Double
Dim trialDaysLostSup1(), trialDaysRestSup1(), trialDaysHospSup1(), injCountSup1() As Double
ReDim trialSup(1 To maxTrials), trialSup1(1 To maxTrials)
ReDim trialDaysLostSup(1 To maxTrials), trialDaysRestSup(1 To maxTrials), trialDaysHospSup(1 To
maxTrials), injCountSup(1 To maxTrials)
ReDim trialDaysLostSup1(1 To maxTrials), trialDaysRestSup1(1 To maxTrials), trialDaysHospSup1(1 To
maxTrials), injCountSup1(1 To maxTrials)

' Initialize Deck Variables
Dim trialDec(), trialDec1() As Double
Dim trialDaysLostDec(), trialDaysRestDec(), trialDaysHospDec(), injCountDec() As Double
Dim trialDaysLostDec1(), trialDaysRestDec1(), trialDaysHospDec1(), injCountDec1() As Double
```

```
ReDim trialDec(1 To maxTrials), trialDec1(1 To maxTrials)
ReDim trialDaysLostDec(1 To maxTrials), trialDaysRestDec(1 To maxTrials), trialDaysHospDec(1 To
maxTrials), injCountDec(1 To maxTrials)
ReDim trialDaysLostDec1(1 To maxTrials), trialDaysRestDec1(1 To maxTrials), trialDaysHospDec1(1 To
maxTrials), injCountDec1(1 To maxTrials)

' Initialize Other Variables
Dim trialOth(), trialOth1() As Double
Dim trialDaysLostOth(), trialDaysRestOth(), trialDaysHospOth(), injCountOth() As Double
Dim trialDaysLostOth1(), trialDaysRestOth1(), trialDaysHospOth1(), injCountOth1() As Double
ReDim trialOth(1 To maxTrials), trialOth1(1 To maxTrials)
ReDim trialDaysLostOth(1 To maxTrials), trialDaysRestOth(1 To maxTrials), trialDaysHospOth(1 To
maxTrials), injCountOth(1 To maxTrials)
ReDim trialDaysLostOth1(1 To maxTrials), trialDaysRestOth1(1 To maxTrials), trialDaysHospOth1(1 To
maxTrials), injCountOth1(1 To maxTrials)

' Initialize Fireman Variables
Dim trialFire(), trialFire1() As Double
Dim trialDaysLostFire(), trialDaysRestFire(), trialDaysHospFire(), injCountFire() As Double
Dim trialDaysLostFire1(), trialDaysRestFire1(), trialDaysHospFire1(), injCountFire1() As Double
ReDim trialFire(1 To maxTrials), trialFire1(1 To maxTrials)
ReDim trialDaysLostFire(1 To maxTrials), trialDaysRestFire(1 To maxTrials), trialDaysHospFire(1 To
maxTrials), injCountFire(1 To maxTrials)
ReDim trialDaysLostFire1(1 To maxTrials), trialDaysRestFire1(1 To maxTrials), trialDaysHospFire1(1 To
maxTrials), injCountFire1(1 To maxTrials)

Let trial = 0
[stat].Value = "Working"
Application.StatusBar = "Working..."

' Perform the number of trials specified
Do While trial < maxTrials
   trial = trial + 1

   ' Simulate the back injury arrival process for Engineers
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muEng]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResEng])
        index = RandGenModule.gen_Resample([indexEng])
        daysLost = daysLost + [daysLostEng].Cells(index).Value
        daysHosp = daysHosp + [daysHospEng].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("F18").Value = totalCost
   Range("B18").Value = count
   trialEng(trial) = totalCost
   trialDaysLostEng(trial) = daysLost
   trialDaysRestEng(trial) = daysRes
   trialDaysHospEng(trial) = daysHosp
   injCountEng(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Engineers changed state
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muEng1]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResEng])
```

```
        index = RandGenModule.gen_Resample([indexEng])
        daysLost = daysLost + [daysLostEng].Cells(index).Value
        daysHosp = daysHosp + [daysHospEng].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("L18").Value = totalCost
   Range("H18").Value = count
   trialEng1(trial) = totalCost
   trialDaysLostEng1(trial) = daysLost
   trialDaysRestEng1(trial) = daysRes
   trialDaysHospEng1(trial) = daysHosp
   injCountEng1(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Aviation
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muAv]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResAv])
        index = RandGenModule.gen_Resample([indexAv])
        daysLost = daysLost + [daysLostAv].Cells(index).Value
        daysHosp = daysHosp + [daysHospAv].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("F19").Value = totalCost
   Range("B19").Value = count
   trialAv(trial) = totalCost
   trialDaysLostAv(trial) = daysLost
   trialDaysRestAv(trial) = daysRes
   trialDaysHospAv(trial) = daysHosp
   injCountAv(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Aviation changed state
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muAv1]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResAv])
        index = RandGenModule.gen_Resample([indexAv])
        daysLost = daysLost + [daysLostAv].Cells(index).Value
        daysHosp = daysHosp + [daysHospAv].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("L19").Value = totalCost
   Range("H19").Value = count
   trialAv1(trial) = totalCost
   trialDaysLostAv1(trial) = daysLost
   trialDaysRestAv1(trial) = daysRes
```

```
   trialDaysHospAvl(trial) = daysHosp
   injCountAvl(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Technical
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muTec]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResTec])
        index = RandGenModule.gen_Resample([indexTec])
        daysLost = daysLost + [daysLostTec].Cells(index).Value
        daysHosp = daysHosp + [daysHospTec].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("F20").Value = totalCost
   Range("B20").Value = count
   trialTec(trial) = totalCost
   trialDaysLostTec(trial) = daysLost
   trialDaysRestTec(trial) = daysRes
   trialDaysHospTec(trial) = daysHosp
   injCountTec(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Technical changed state
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muTec1]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResTec])
        index = RandGenModule.gen_Resample([indexTec])
        daysLost = daysLost + [daysLostTec].Cells(index).Value
        daysHosp = daysHosp + [daysHospTec].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("L20").Value = totalCost
   Range("H20").Value = count
   trialTec1(trial) = totalCost
   trialDaysLostTec1(trial) = daysLost
   trialDaysRestTec1(trial) = daysRes
   trialDaysHospTec1(trial) = daysHosp
   injCountTec1(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Seaman
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
```

```
      d = d + Int(RandGenModule.gen_Exponential([muSea]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResSea])
        index = RandGenModule.gen_Resample([indexSea])
        daysLost = daysLost + [daysLostSea].Cells(index).Value
        daysHosp = daysHosp + [daysHospSea].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("F21").Value = totalCost
   Range("B21").Value = count
   trialSea(trial) = totalCost
   trialDaysLostSea(trial) = daysLost
   trialDaysRestSea(trial) = daysRes
   trialDaysHospSea(trial) = daysHosp
   injCountSea(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Seaman changed state
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muSea1]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResSea])
        index = RandGenModule.gen_Resample([indexSea])
        daysLost = daysLost + [daysLostSea].Cells(index).Value
        daysHosp = daysHosp + [daysHospSea].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("L21").Value = totalCost
   Range("H21").Value = count
   trialSea1(trial) = totalCost
   trialDaysLostSea1(trial) = daysLost
   trialDaysRestSea1(trial) = daysRes
   trialDaysHospSea1(trial) = daysHosp
   injCountSea1(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Supply
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muSup]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResSup])
        index = RandGenModule.gen_Resample([indexSup])
        daysLost = daysLost + [daysLostSup].Cells(index).Value
        daysHosp = daysHosp + [daysHospSup].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("F22").Value = totalCost
   Range("B22").Value = count
```

```
   trialSup(trial) = totalCost
   trialDaysLostSup(trial) = daysLost
   trialDaysRestSup(trial) = daysRes
   trialDaysHospSup(trial) = daysHosp
   injCountSup(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Supply changed state
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muSup1]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResSup])
        index = RandGenModule.gen_Resample([indexSup])
        daysLost = daysLost + [daysLostSup].Cells(index).Value
        daysHosp = daysHosp + [daysHospSup].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("L22").Value = totalCost
   Range("H22").Value = count
   trialSup1(trial) = totalCost
   trialDaysLostSup1(trial) = daysLost
   trialDaysRestSup1(trial) = daysRes
   trialDaysHospSup1(trial) = daysHosp
   injCountSup1(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Deck
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muDec]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResDec])
        index = RandGenModule.gen_Resample([indexDec])
        daysLost = daysLost + [daysLostDec].Cells(index).Value
        daysHosp = daysHosp + [daysHospDec].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("F23").Value = totalCost
   Range("B23").Value = count
   trialDec(trial) = totalCost
   trialDaysLostDec(trial) = daysLost
   trialDaysRestDec(trial) = daysRes
   trialDaysHospDec(trial) = daysHosp
   injCountDec(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Deck changed state
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0
```

```
   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muDec1]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResDec])
        index = RandGenModule.gen_Resample([indexDec])
        daysLost = daysLost + [daysLostDec].Cells(index).Value
        daysHosp = daysHosp + [daysHospDec].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("L23").Value = totalCost
   Range("H23").Value = count
   trialDec1(trial) = totalCost
   trialDaysLostDec1(trial) = daysLost
   trialDaysRestDec1(trial) = daysRes
   trialDaysHospDec1(trial) = daysHosp
   injCountDec1(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Other
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muOth]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResOth])
        index = RandGenModule.gen_Resample([indexOth])
        daysLost = daysLost + [daysLostOth].Cells(index).Value
        daysHosp = daysHosp + [daysHospOth].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("F24").Value = totalCost
   Range("B24").Value = count
   trialOth(trial) = totalCost
   trialDaysLostOth(trial) = daysLost
   trialDaysRestOth(trial) = daysRes
   trialDaysHospOth(trial) = daysHosp
   injCountOth(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Other changed state
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muOth1]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResOth])
        index = RandGenModule.gen_Resample([indexOth])
        daysLost = daysLost + [daysLostOth].Cells(index).Value
        daysHosp = daysHosp + [daysHospOth].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
```

```
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("L24").Value = totalCost
   Range("H24").Value = count
   trialOth1(trial) = totalCost
   trialDaysLostOth1(trial) = daysLost
   trialDaysRestOth1(trial) = daysRes
   trialDaysHospOth1(trial) = daysHosp
   injCountOth1(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Fire
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muFire]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResFire])
        index = RandGenModule.gen_Resample([indexFire])
        daysLost = daysLost + [daysLostFire].Cells(index).Value
        daysHosp = daysHosp + [daysHospFire].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("F25").Value = totalCost
   Range("B25").Value = count
   trialFire(trial) = totalCost
   trialDaysLostFire(trial) = daysLost
   trialDaysRestFire(trial) = daysRes
   trialDaysHospFire(trial) = daysHosp
   injCountFire(trial) = count
   Calculate

   ' Simulate the back injury arrival process for Fireman changed state
   d = 0
   index = 0
   daysRes = 0
   daysLost = 0
   daysHosp = 0
   count = 0
   totalCost = 0

   ' Continue to incur injuries until end period
   Do While d < maxDays
      d = d + Int(RandGenModule.gen_Exponential([muFire1]))
      If d < maxDays Then
        daysRes = daysRes + RandGenModule.gen_Resample([daysResFire])
        index = RandGenModule.gen_Resample([indexFire])
        daysLost = daysLost + [daysLostFire].Cells(index).Value
        daysHosp = daysHosp + [daysHospFire].Cells(index).Value
        count = count + 1
      End If
   Loop

   ' Record statistics for the period
   totalCost = daysRes * [costPerDayRes].Value + daysLost * [costPerDayLost] + daysHosp *
[costPerDayHosp]
   Range("L25").Value = totalCost
   Range("H25").Value = count
   trialFire1(trial) = totalCost
   trialDaysLostFire1(trial) = daysLost
   trialDaysRestFire1(trial) = daysRes
   trialDaysHospFire1(trial) = daysHosp
   injCountFire1(trial) = count
   Calculate

[trialComp].Value = trial
Loop

' Generate statistics from arrays for average injury count, average number of days lost, average
```

```
' number of days restricted, average number of days hospitalized, average cost per trial period,
' and stand deviation of cost per trial period for the changed and unchanged states of each
' job family.

Range("B18").Value = Application.Average(injCountEng)
Range("C18").Value = Application.Average(trialDaysLostEng)
Range("D18").Value = Application.Average(trialDaysRestEng)
Range("E18").Value = Application.Average(trialDaysHospEng)
Range("F18").Value = Application.Average(trialEng)
Range("G18").Value = Application.StDev(trialEng) / maxTrials ^ 0.5

Range("H18").Value = Application.Average(injCountEng1)
Range("I18").Value = Application.Average(trialDaysLostEng1)
Range("J18").Value = Application.Average(trialDaysRestEng1)
Range("K18").Value = Application.Average(trialDaysHospEng1)
Range("L18").Value = Application.Average(trialEng1)
Range("M18").Value = Application.StDev(trialEng1) / maxTrials ^ 0.5

Range("B19").Value = Application.Average(injCountAv)
Range("C19").Value = Application.Average(trialDaysLostAv)
Range("D19").Value = Application.Average(trialDaysRestAv)
Range("E19").Value = Application.Average(trialDaysHospAv)
Range("F19").Value = Application.Average(trialAv)
Range("G19").Value = Application.StDev(trialAv) / maxTrials ^ 0.5

Range("H19").Value = Application.Average(injCountAv1)
Range("I19").Value = Application.Average(trialDaysLostAv1)
Range("J19").Value = Application.Average(trialDaysRestAv1)
Range("K19").Value = Application.Average(trialDaysHospAv1)
Range("L19").Value = Application.Average(trialAv1)
Range("M19").Value = Application.StDev(trialAv1) / maxTrials ^ 0.5

Range("B20").Value = Application.Average(injCountTec)
Range("C20").Value = Application.Average(trialDaysLostTec)
Range("D20").Value = Application.Average(trialDaysRestTec)
Range("E20").Value = Application.Average(trialDaysHospTec)
Range("F20").Value = Application.Average(trialTec)
Range("G20").Value = Application.StDev(trialTec) / maxTrials ^ 0.5

Range("H20").Value = Application.Average(injCountTec1)
Range("I20").Value = Application.Average(trialDaysLostTec1)
Range("J20").Value = Application.Average(trialDaysRestTec1)
Range("K20").Value = Application.Average(trialDaysHospTec1)
Range("L20").Value = Application.Average(trialTec1)
Range("M20").Value = Application.StDev(trialTec1) / maxTrials ^ 0.5

Range("B21").Value = Application.Average(injCountSea)
Range("C21").Value = Application.Average(trialDaysLostSea)
Range("D21").Value = Application.Average(trialDaysRestSea)
Range("E21").Value = Application.Average(trialDaysHospSea)
Range("F21").Value = Application.Average(trialSea)
Range("G21").Value = Application.StDev(trialSea) / maxTrials ^ 0.5

Range("H21").Value = Application.Average(injCountSea1)
Range("I21").Value = Application.Average(trialDaysLostSea1)
Range("J21").Value = Application.Average(trialDaysRestSea1)
Range("K21").Value = Application.Average(trialDaysHospSea1)
Range("L21").Value = Application.Average(trialSea1)
Range("M21").Value = Application.StDev(trialSea1) / maxTrials ^ 0.5

Range("B22").Value = Application.Average(injCountSup)
Range("C22").Value = Application.Average(trialDaysLostSup)
Range("D22").Value = Application.Average(trialDaysRestSup)
Range("E22").Value = Application.Average(trialDaysHospSup)
Range("F22").Value = Application.Average(trialSup)
Range("G22").Value = Application.StDev(trialSup) / maxTrials ^ 0.5

Range("H22").Value = Application.Average(injCountSup1)
Range("I22").Value = Application.Average(trialDaysLostSup1)
Range("J22").Value = Application.Average(trialDaysRestSup1)
Range("K22").Value = Application.Average(trialDaysHospSup1)
Range("L22").Value = Application.Average(trialSup1)
Range("M22").Value = Application.StDev(trialSup1) / maxTrials ^ 0.5

Range("B23").Value = Application.Average(injCountDec)
Range("C23").Value = Application.Average(trialDaysLostDec)
Range("D23").Value = Application.Average(trialDaysRestDec)
Range("E23").Value = Application.Average(trialDaysHospDec)
Range("F23").Value = Application.Average(trialDec)
Range("G23").Value = Application.StDev(trialDec) / maxTrials ^ 0.5
```

```
Range("H23").Value = Application.Average(injCountDec1)
Range("I23").Value = Application.Average(trialDaysLostDec1)
Range("J23").Value = Application.Average(trialDaysRestDec1)
Range("K23").Value = Application.Average(trialDaysHospDec1)
Range("L23").Value = Application.Average(trialDec1)
Range("M23").Value = Application.StDev(trialDec1) / maxTrials ^ 0.5

Range("B24").Value = Application.Average(injCountOth)
Range("C24").Value = Application.Average(trialDaysLostOth)
Range("D24").Value = Application.Average(trialDaysRestOth)
Range("E24").Value = Application.Average(trialDaysHospOth)
Range("F24").Value = Application.Average(trialOth)
Range("G24").Value = Application.StDev(trialOth) / maxTrials ^ 0.5

Range("H24").Value = Application.Average(injCountOth1)
Range("I24").Value = Application.Average(trialDaysLostOth1)
Range("J24").Value = Application.Average(trialDaysRestOth1)
Range("K24").Value = Application.Average(trialDaysHospOth1)
Range("L24").Value = Application.Average(trialOth1)
Range("M24").Value = Application.StDev(trialOth1) / maxTrials ^ 0.5

Range("B25").Value = Application.Average(injCountFire)
Range("C25").Value = Application.Average(trialDaysLostFire)
Range("D25").Value = Application.Average(trialDaysRestFire)
Range("E25").Value = Application.Average(trialDaysHospFire)
Range("F25").Value = Application.Average(trialFire)
Range("G25").Value = Application.StDev(trialFire) / maxTrials ^ 0.5

Range("H25").Value = Application.Average(injCountFire1)
Range("I25").Value = Application.Average(trialDaysLostFire1)
Range("J25").Value = Application.Average(trialDaysRestFire1)
Range("K25").Value = Application.Average(trialDaysHospFire1)
Range("L25").Value = Application.Average(trialFire1)
Range("M25").Value = Application.StDev(trialFire1) / maxTrials ^ 0.5

Application.StatusBar = False
Range("stat").Value = "Done"
End Sub
```

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